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Title: Bad Foils in Simulated Opacity Experiments

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Intended for: Onsite seminar on 12/3 at 1 PM in JRO 1/2

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Bad Foils in Simulated Opacity Experiments

Peer Review Meeting

**A. S. Liao, M. E. Sherrill, I. O. Usov, D. R. Vodnik,
C. J. Fontes, T. J. Urbatsch**

12/3/2018



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Agenda

12/3/2018

1 PM

JRO 1/2

- **Opacity in HED Astrophysics**
- **HED Opacity Experiments**
- **Bad Foils in Opacity Experiments**
- **Bad Foils in Simulated Opacity Experiments**



Agenda

12/3/2018

1 PM

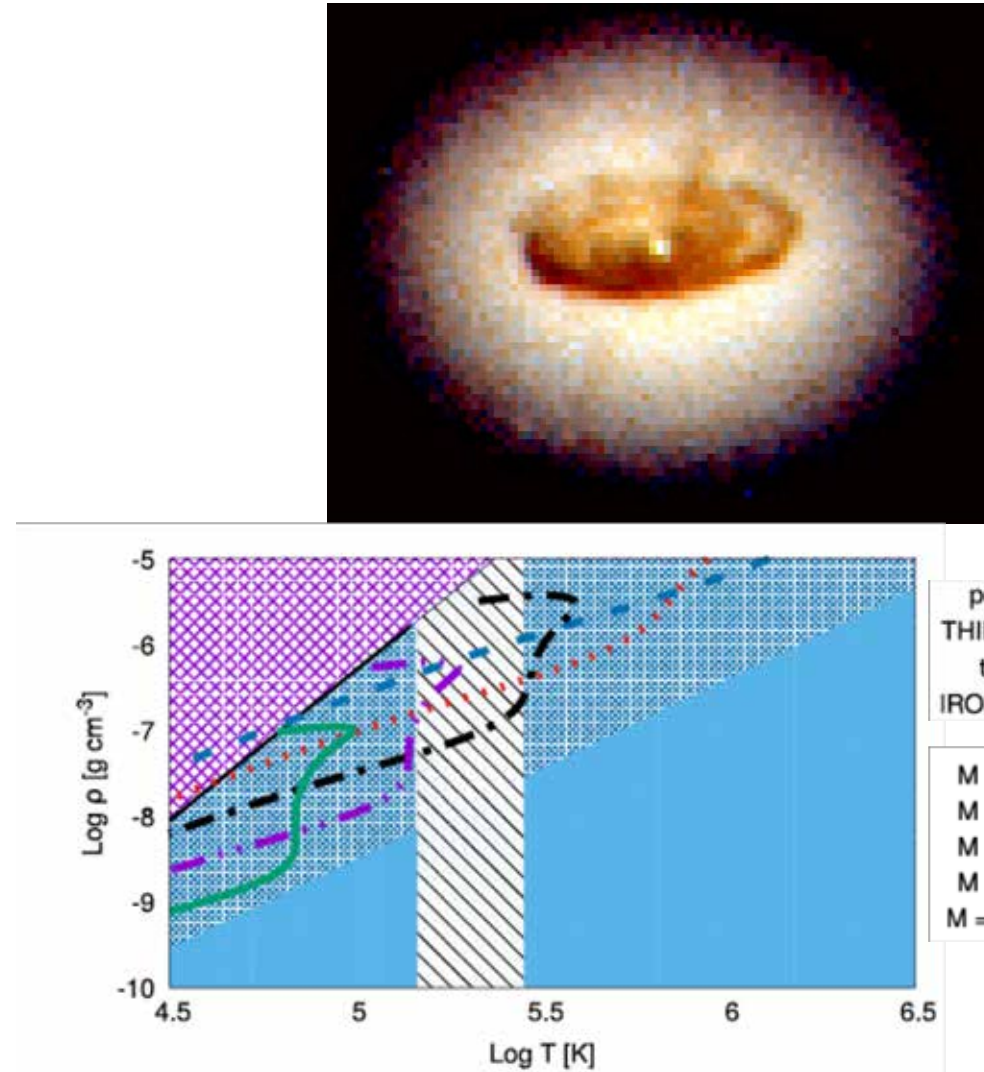
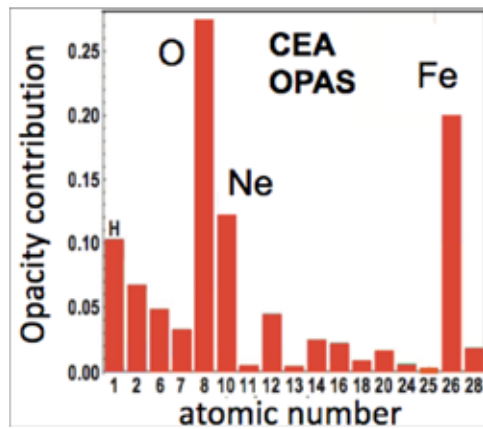
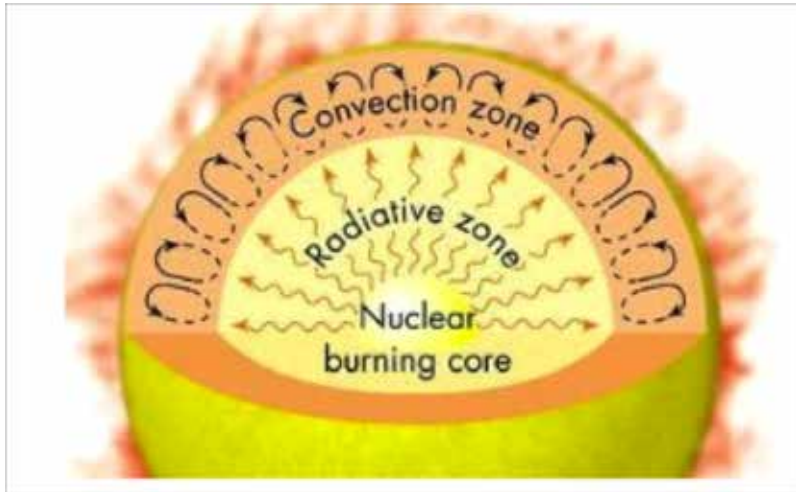
JRO 1/2

- Opacity in HED Astrophysics
- HED Opacity Experiments
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Why Study Opacity of HED Metals?

Images (left): G. Djorgovski & T. Nagayama & C. Blanchard



SMBH disk in core of NGC 4261: L. Ferrarese et al.
SMBH disk r-T profiles and κ_{Fe} : M. Grz̧dzielski et al.

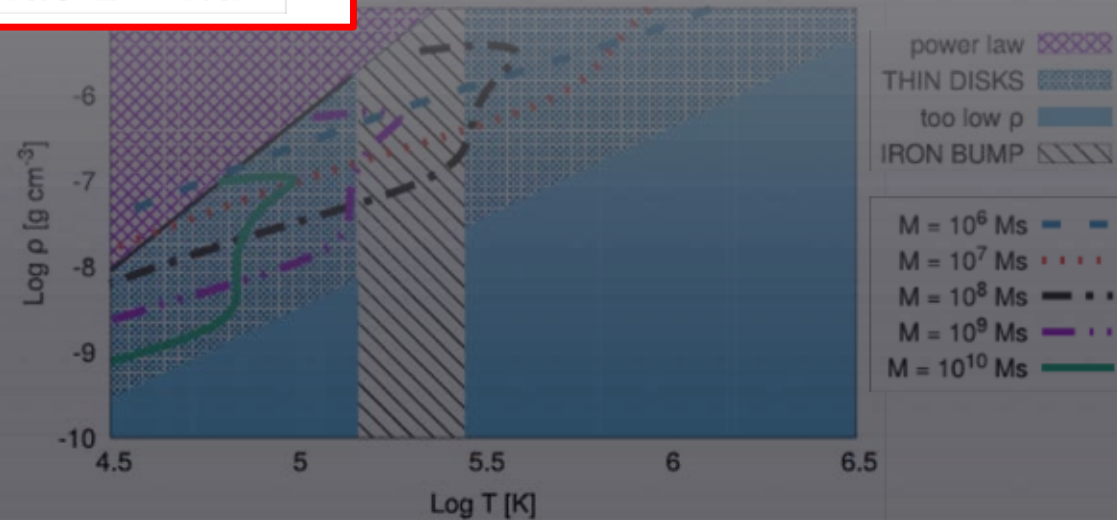
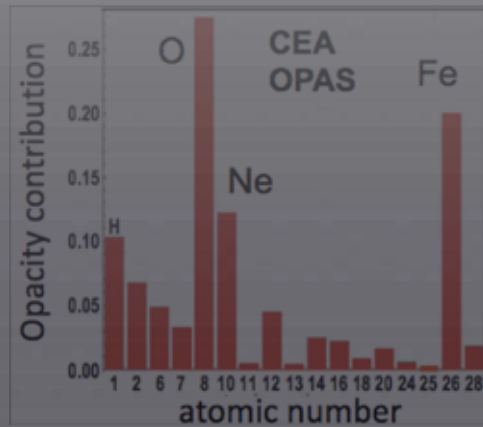
Why Study Opacity of HED Metals?

Images (left): G. Djorgovski & T. Nagayama & C. Blanchard



Radiative energy transport through hydrostatic system predicts system structure!

$$\frac{dT}{dr} = -\frac{3}{4ac} \frac{\kappa \rho}{T^3} \frac{L}{4\pi r^2}$$



SMBH disk in core of NGC 4261: L. Ferrarese et al.
SMBH disk r-T profiles and κ_{Fe} : M. Grz̧dzielski et al.

Locating the Convective Zone Base

Onset of convection when
adiabatic value exceeded!

$$\frac{dT}{dr} = -\frac{3}{4ac} \frac{\kappa \rho}{T^3} \frac{L}{4\pi r^2}$$

Locating the Convective Zone Base

Table 2

A comparison of solar abundances of some elements in tables of Anders and Grevesse (1989, AG89), Grevesse and Noels (1993, GN93), Grevesse and Sauval (1998, GS98) and Asplund et al. (2005b, AGS05)

Element	Z	AG89	GN93	GS98	AGS05
C	6	8.56 ± 0.04	8.55 ± 0.05	8.52 ± 0.06	8.39 ± 0.05
N	7	8.05 ± 0.04	7.97 ± 0.05	7.92 ± 0.06	7.78 ± 0.06
O	8	8.93 ± 0.04	8.87 ± 0.04	8.83 ± 0.06	8.66 ± 0.05
Ne	10	8.09 ± 0.10	8.07 ± 0.06	8.08 ± 0.06	7.84 ± 0.06
Na	11	6.33 ± 0.03	6.33 ± 0.03	6.33 ± 0.03	6.17 ± 0.04
Mg	12	7.58 ± 0.05	7.58 ± 0.05	7.58 ± 0.05	7.53 ± 0.09
Al	13	6.47 ± 0.07	6.47 ± 0.07	6.47 ± 0.07	6.37 ± 0.06
Si	14	7.55 ± 0.05	7.55 ± 0.05	7.55 ± 0.05	7.51 ± 0.04
P	15	5.45 ± 0.04	5.45 ± 0.04	5.45 ± 0.04	5.36 ± 0.04
S	16	7.21 ± 0.06	7.21 ± 0.06	7.33 ± 0.11	7.14 ± 0.05
Cl	17	5.50 ± 0.30	5.50 ± 0.30	5.50 ± 0.30	5.50 ± 0.30
Ar	18	6.56 ± 0.10	6.60 ± 0.14	6.40 ± 0.06	6.18 ± 0.08
K	19	5.12 ± 0.13	5.12 ± 0.13	5.12 ± 0.13	5.08 ± 0.07
Ca	20	6.36 ± 0.02	6.36 ± 0.02	6.36 ± 0.02	6.31 ± 0.04
Ti	22	4.99 ± 0.02	5.04 ± 0.02	5.02 ± 0.06	4.90 ± 0.06
Cr	24	5.67 ± 0.03	5.67 ± 0.03	5.67 ± 0.03	5.64 ± 0.10
Mn	25	5.39 ± 0.03	5.39 ± 0.03	5.39 ± 0.03	5.39 ± 0.03
Fe	26	7.67 ± 0.03	7.51 ± 0.01	7.50 ± 0.05	7.45 ± 0.05
Ni	28	6.25 ± 0.04	6.25 ± 0.04	6.25 ± 0.04	6.23 ± 0.04
Z/X		$.0274 \pm .0016$	$.0244 \pm .0014$	$.0231 \pm .0018$	$.0165 \pm .0011$

Abundances are in units of $\log_{10}(A/H) + 12$.

Locating the Convective Zone Base

Onset of convection when
adiabatic value exceeded!

$$\frac{dT}{dr} = -\frac{3}{4ac} \frac{\kappa \rho}{T^3} \frac{L}{4\pi r^2}$$

Table 3

The position of the base of the convection zone (r_b) and the helium abundance Y_s in the convection zone for different solar models

Reference	Z/X	r_b	Y_s	Remarks
Basu et al. (2000)	0.0245	0.7123	0.2453	GN93
Bahcall et al. (2001)	0.0229	0.7140	0.2437	GS98
Montalbán et al. (2004)	0.0245	0.714	0.246	GN93
Montalbán et al. (2004)	0.0177	0.727	0.243	
Montalbán et al. (2004)	0.0177	0.723	0.248	Enhanced opacity
Montalbán et al. (2004)	0.0177	0.718	0.249	Enhanced opacity
Montalbán et al. (2004)	0.0177	0.714	0.226	Enhanced diffusion
Montalbán et al. (2004)	0.0177	0.717	0.239	Enhanced diffusion & opacity
Turck-Chièze et al. (2004)	0.0172	0.7285	0.2353	
Turck-Chièze et al. (2004)	0.0172	0.7312	0.2407	Mixing in tachocline
Bahcall et al. (2005a)	0.0176	0.7259	0.238	
Bahcall et al. (2005a)	0.0176	0.7133	0.239	21% increase in opacity
Bahcall et al. (2005a)	0.0176	0.7162	0.243	11% increase in opacity
Bahcall et al. (2005b)	0.0192	0.7174	0.2411	OP, increased Ne
Bahcall et al. (2005b)	0.0207	0.7146	0.2439	OP, increased Ne, CNO
Bahcall et al. (2005c)	0.0229	0.7138	0.243	GS98, OP opacity
Bahcall et al. (2005c)	0.0165	0.7280	0.229	AGS05, OP opacity
Guzik et al. (2005)	0.0244	0.7133	0.2419	GN93
Guzik et al. (2005)	0.0196	0.7022	0.1926	Enhanced diffusion
Guzik et al. (2005)	0.0186	0.7283	0.2339	Enhanced Z diffusion
Guzik et al. (2005)	0.0206	0.7175	0.2269	Enhanced diffusion
Guzik et al. (2005)	0.0173	0.7406	0.2541	Enhanced diffusion
Yang and Bi (2007)	0.0174	0.7335	0.2294	
Yang and Bi (2007)	0.0176	0.7168	0.2225	Enhanced diffusion
Castro et al. (2007)	0.0164	0.730	0.223	
Castro et al. (2007)	0.0165	0.732	0.240	GS98 + low-Z accretion
Castro et al. (2007)	0.0165	0.712	0.249	GS98 + low-Z accretion & Mixing & overshoot

Unless mentioned otherwise, the models were calculated with OPAL opacities.

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If abundances fall, then opacity must rise!

S. Basu et al. (2008)

Unless mentioned otherwise, the models were calculated with OPAL opacities.

Agenda

12/3/2018

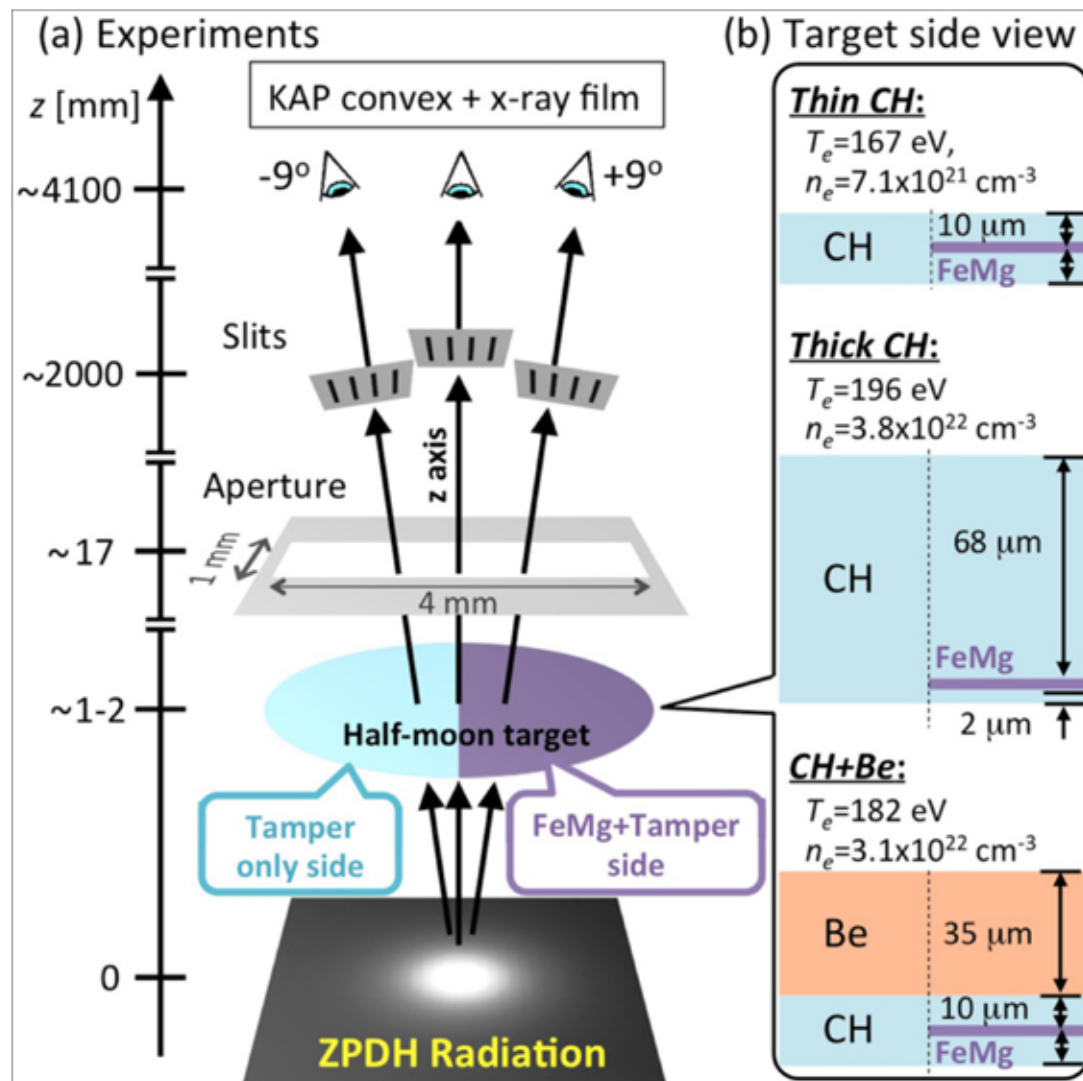
1 PM

JRO 1/2

- **Opacity in HED Astrophysics**
- **HED Opacity Experiments**
- **Bad Foils in Opacity Experiments**
- **Bad Foils in Simulated Opacity Experiments**

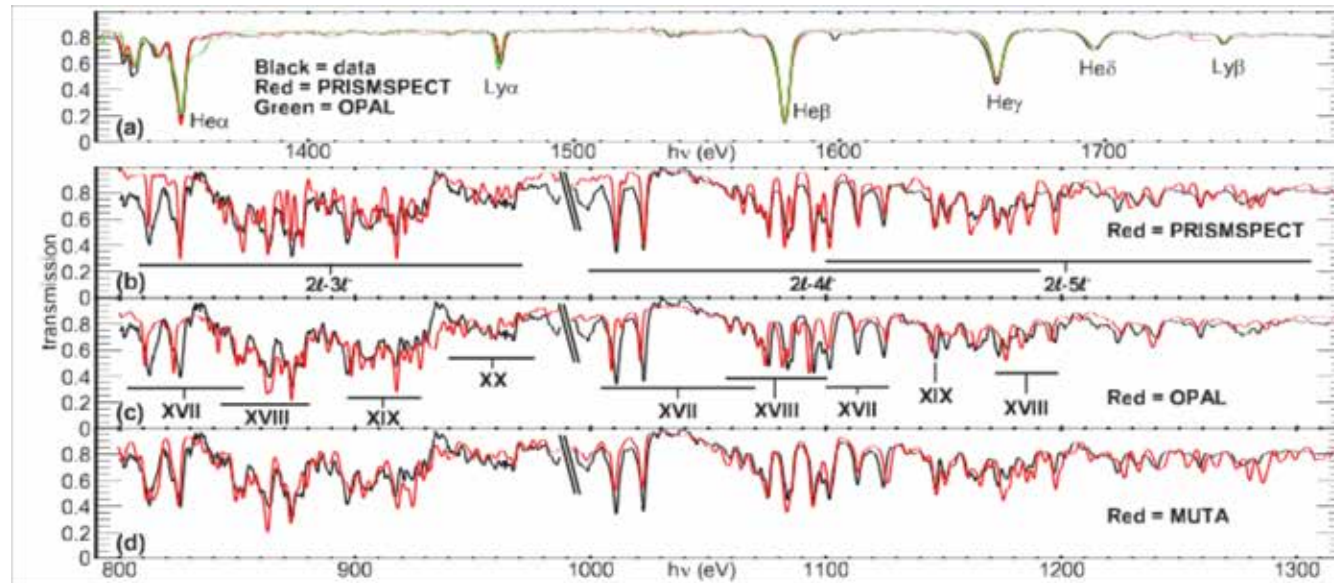


Opacity Experiments on Z



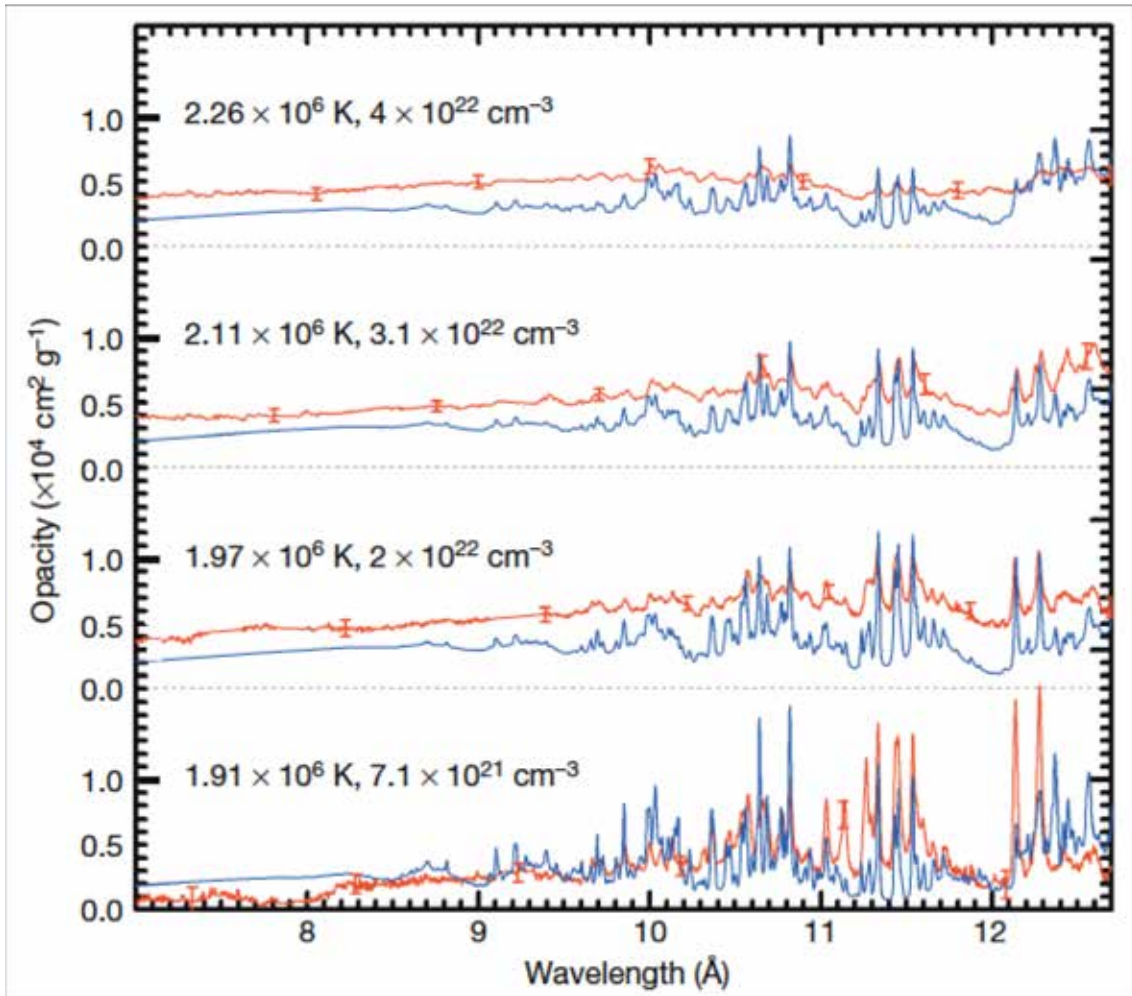
T. Nagayama et al. (2016)

Opacity Experiments on Z



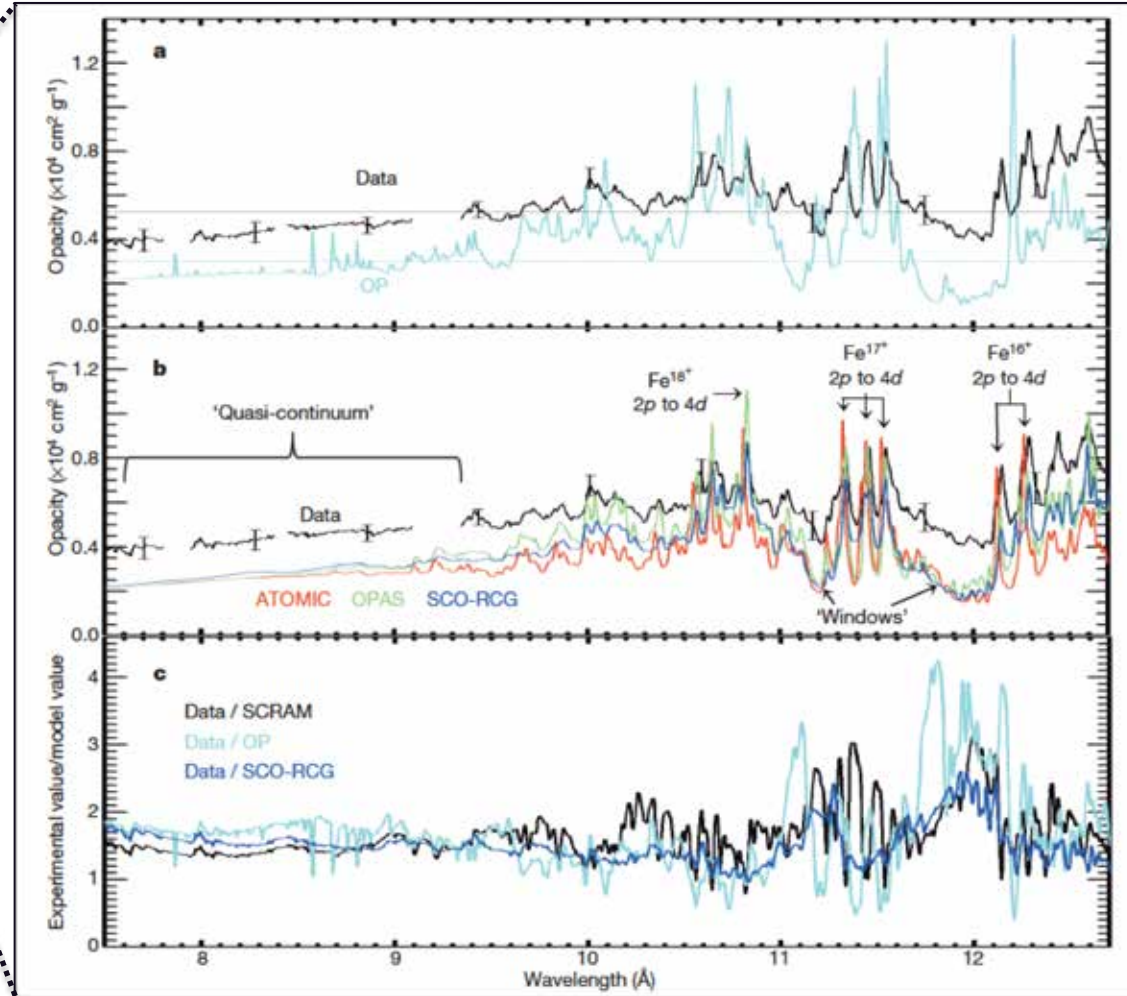
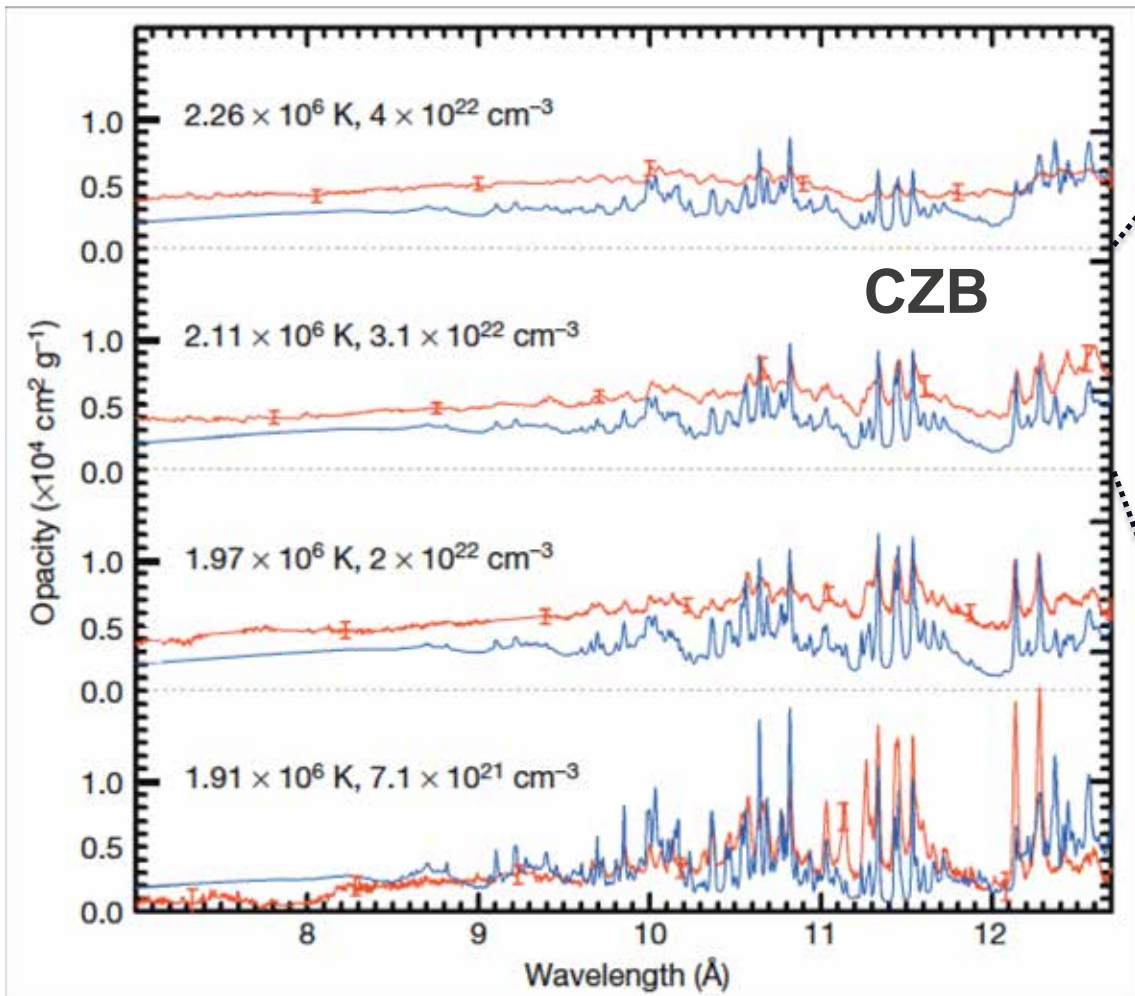
J. Bailey et al. (2007)

Opacity Experiments on Z



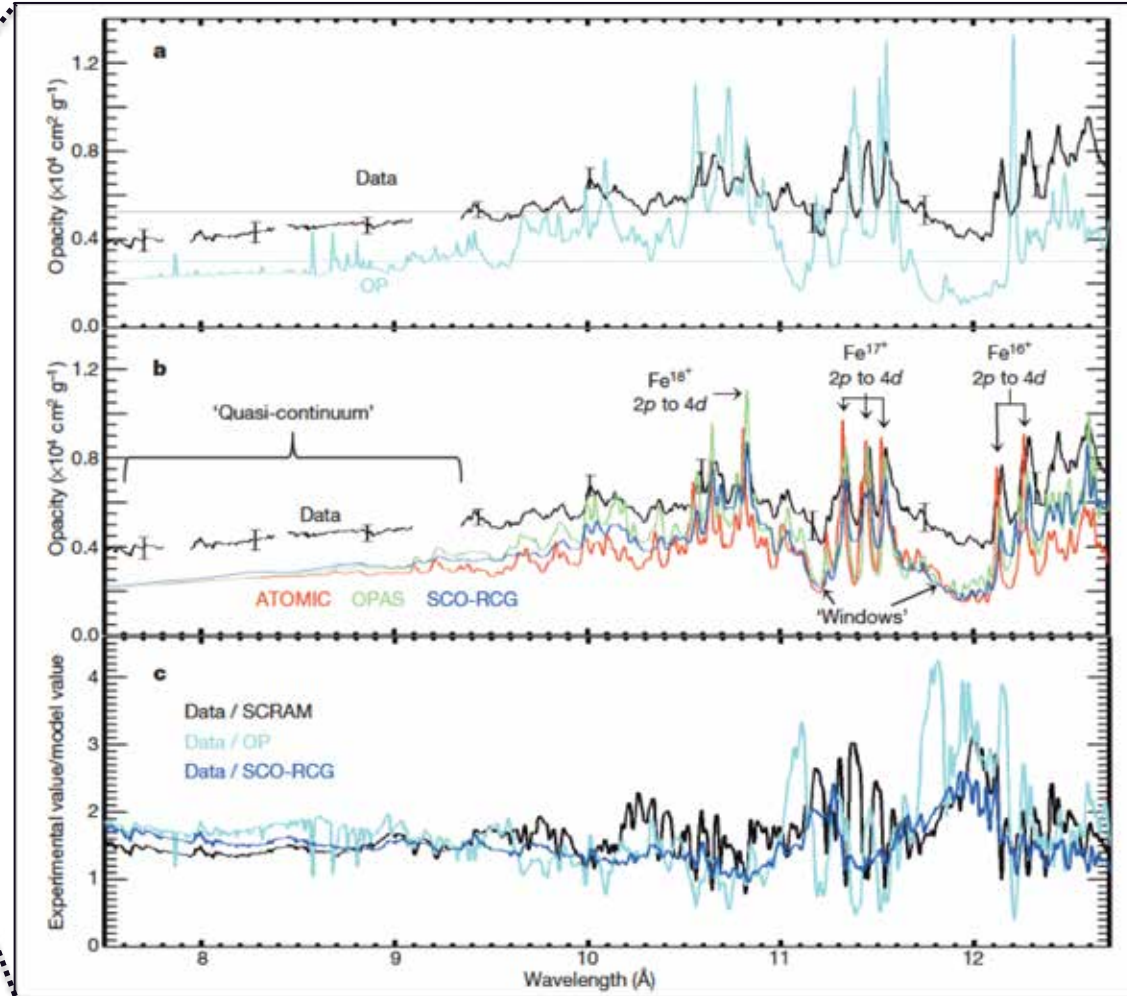
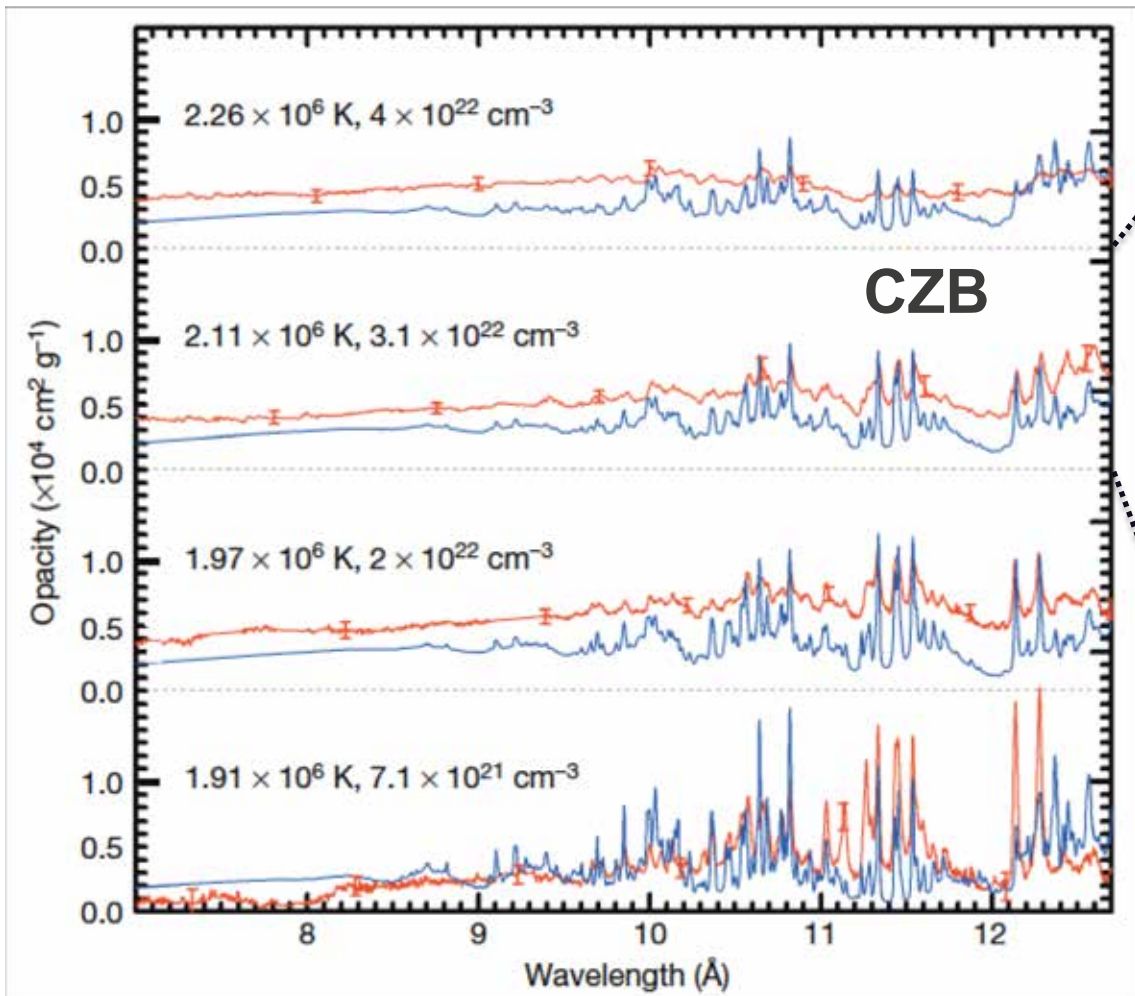
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Opacity Experiments on Z



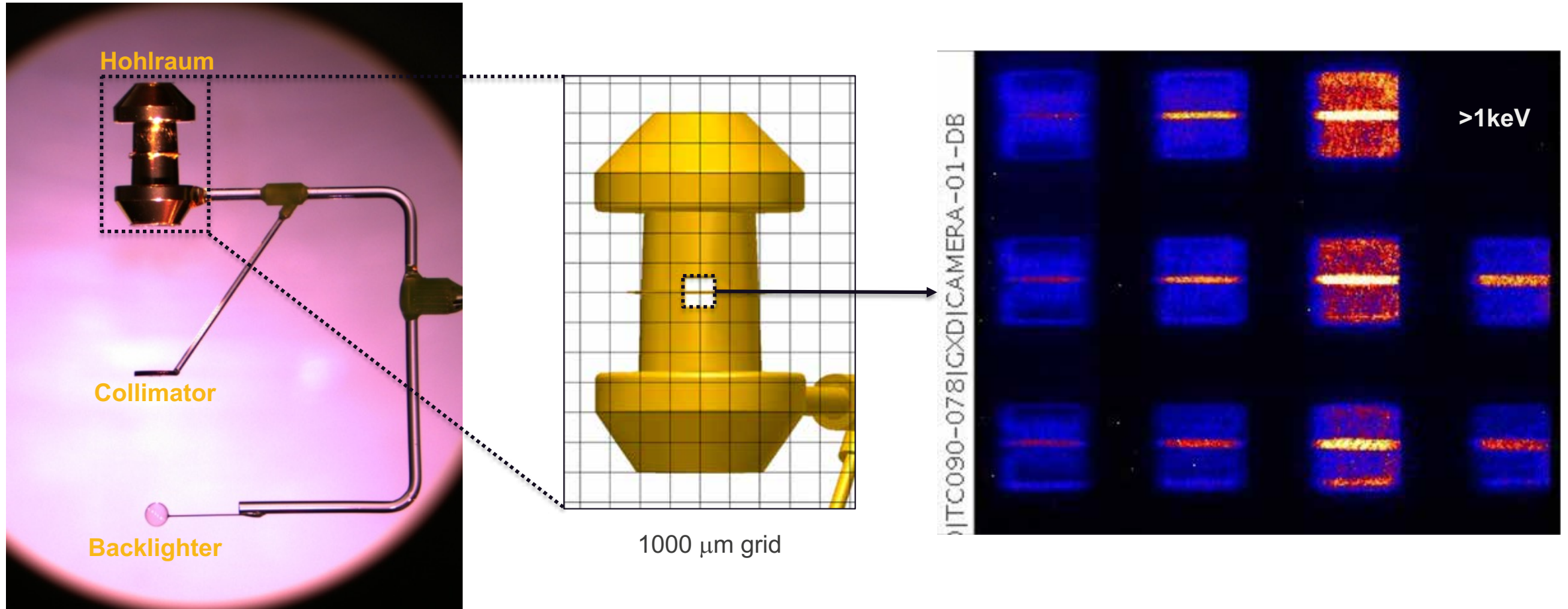
J. Bailey et al. (2015)

Opacity Experiments on Z



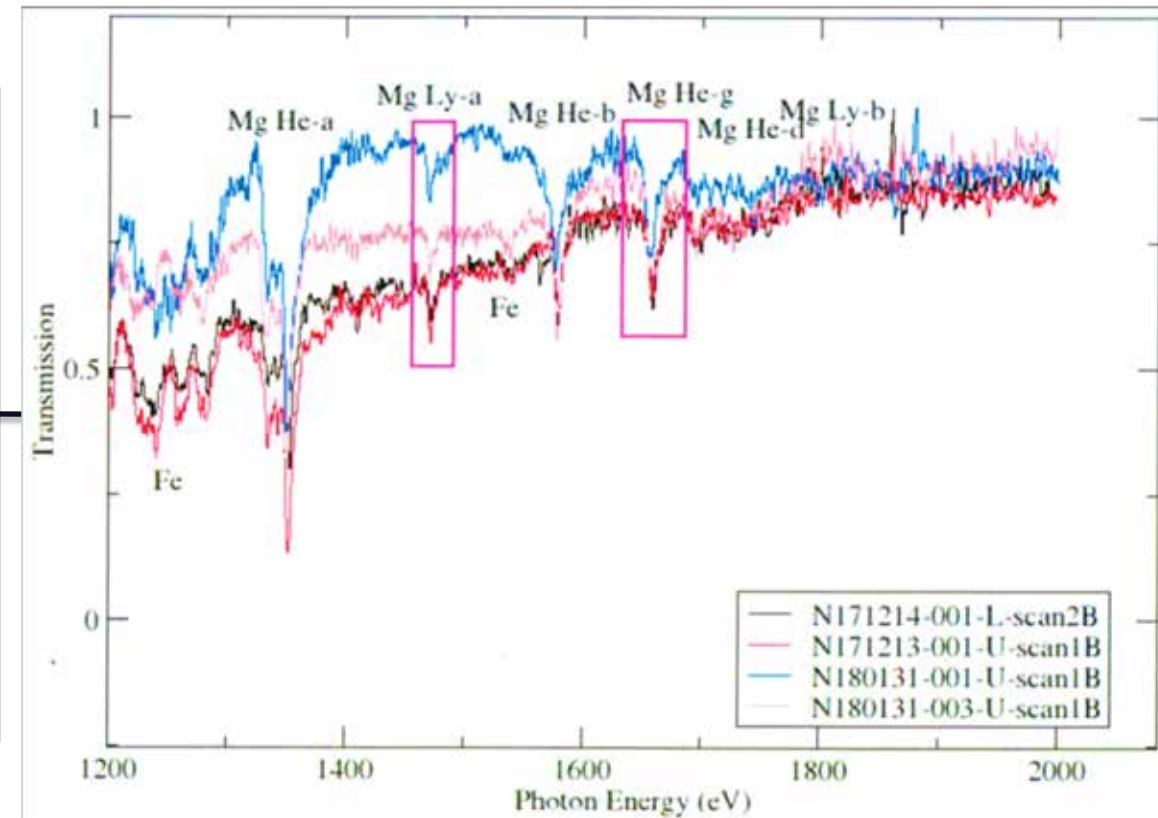
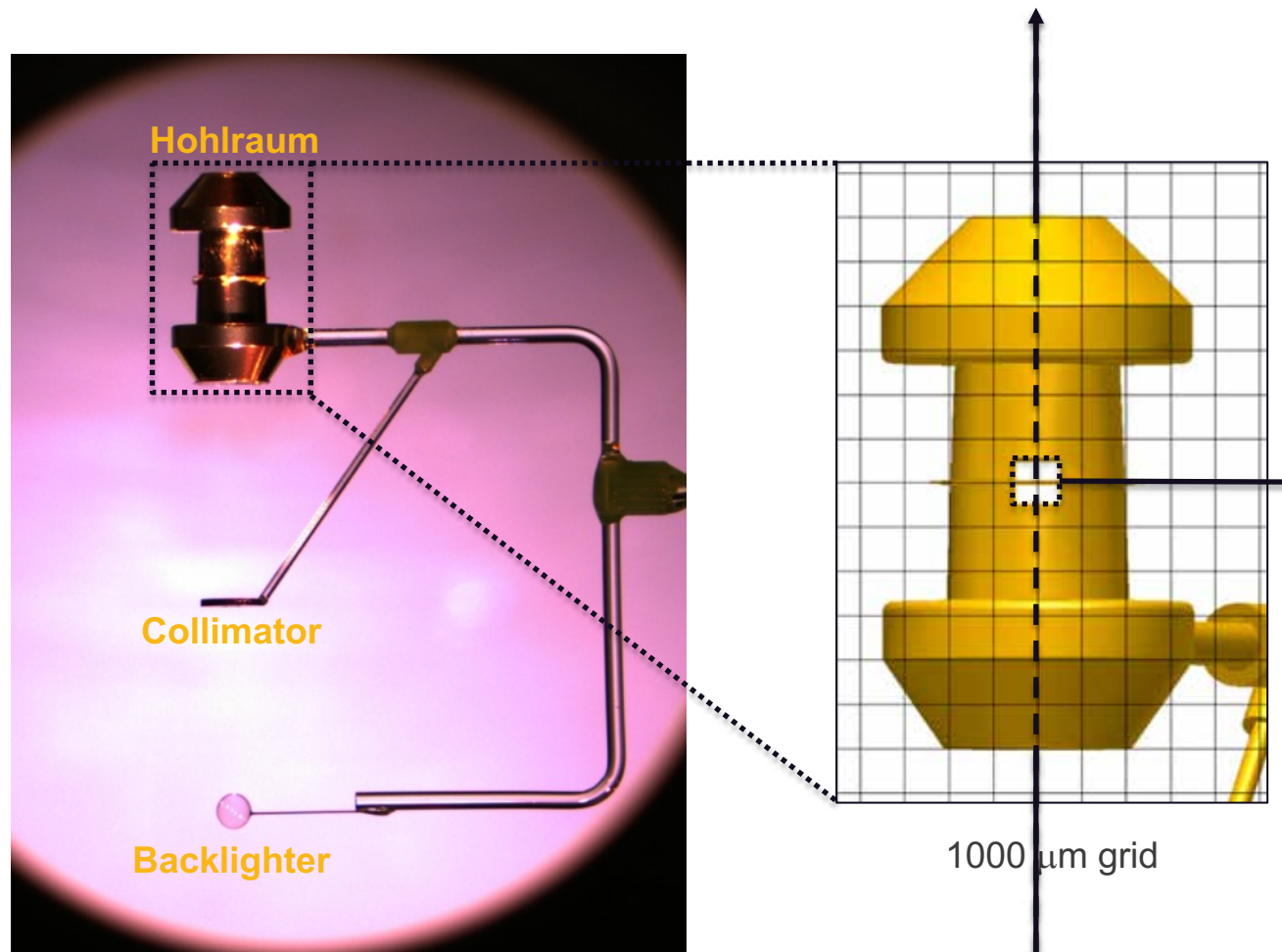
If abundances fall, then opacity must rise!

Opacity Experiments on NIF



Images: T. Cardenas, R. Heeter, H. Johns

Opacity Experiments on NIF



Images: T. Cardenas, R. Heeter, H. Johns

Agenda

12/3/2018

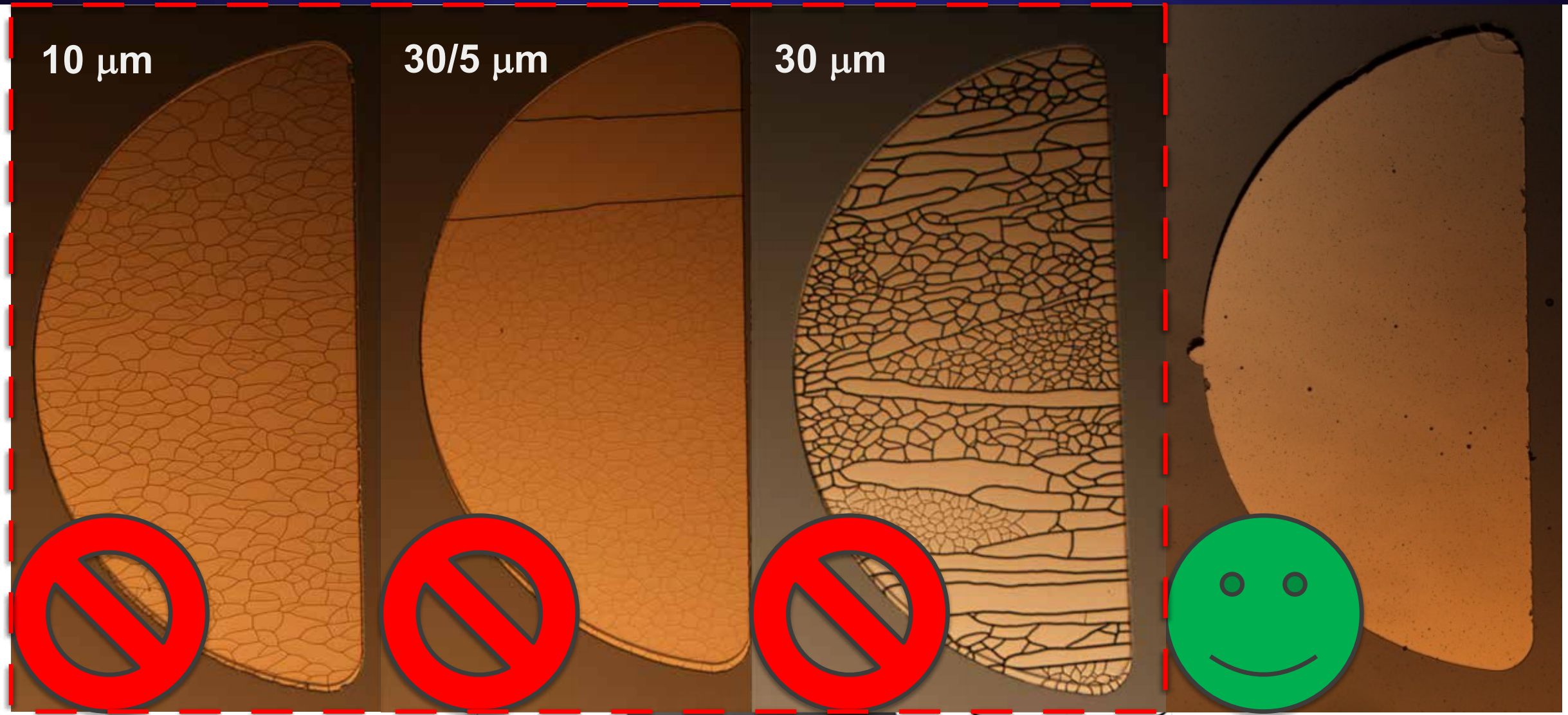
1 PM

JRO 1/2

- **Opacity in HED Astrophysics**
- **HED Opacity Experiments**
- **Bad Foils in Opacity Experiments**
- **Bad Foils in Simulated Opacity Experiments**

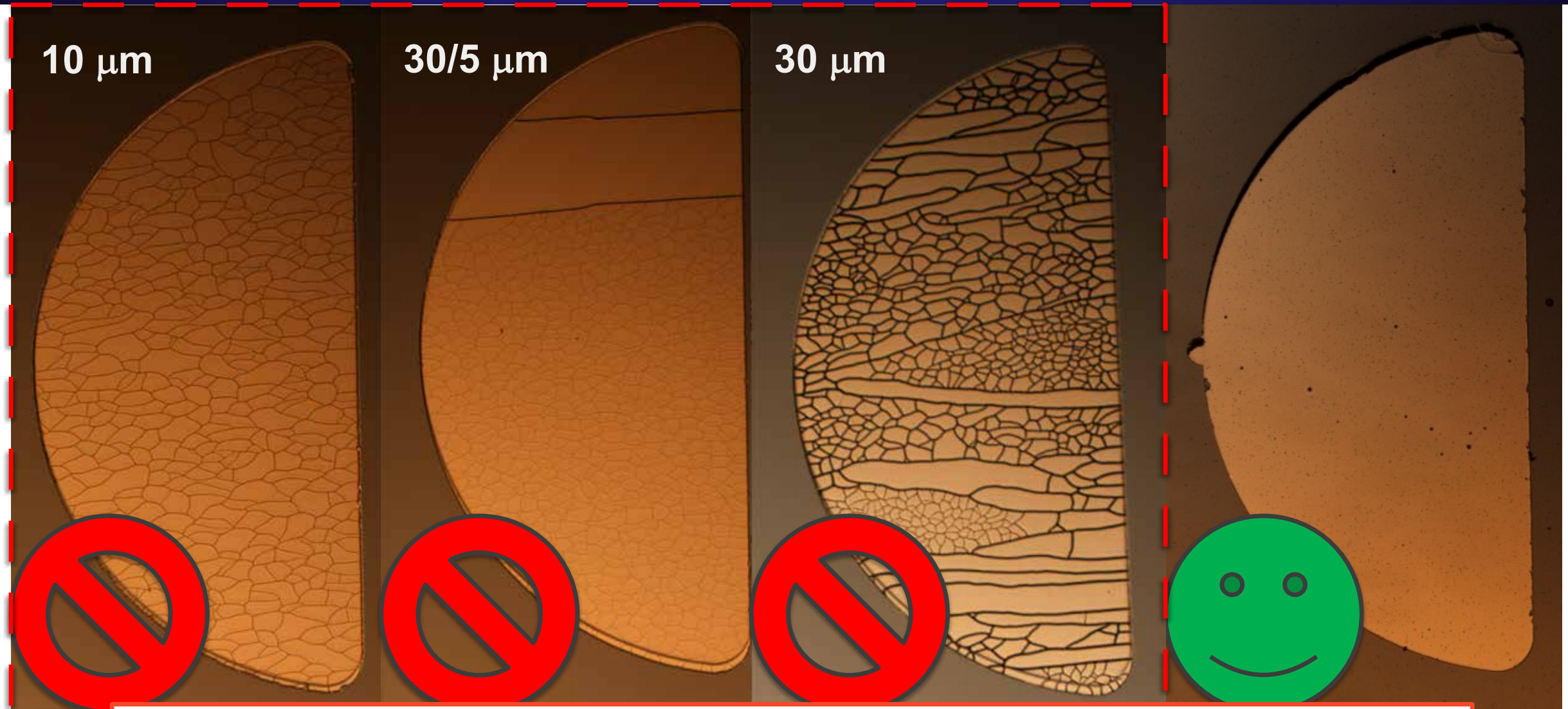


What are Bad Foils?



Images: I. Usov

What are Bad Foils?



Higher incident rate in some classes of samples

How are Bad Foils Bad?



Nominal
(edge-on)

How are Bad Foils Bad?

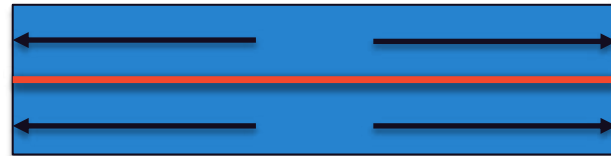
1. Stress defects



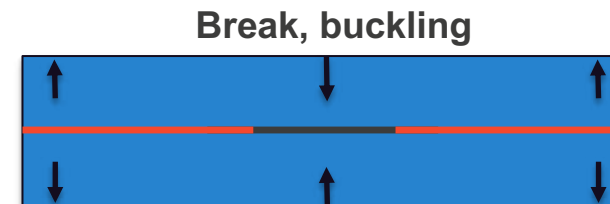
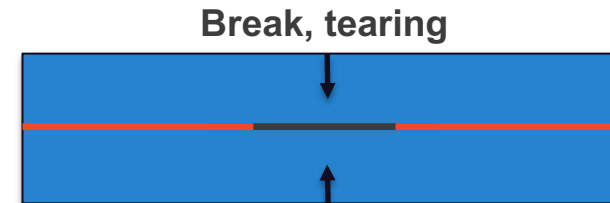
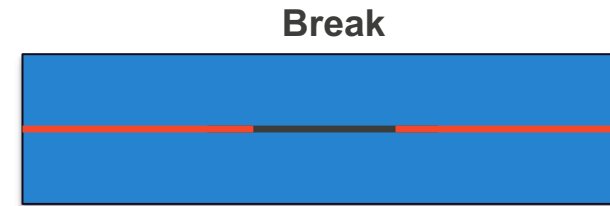
Nominal
(edge-on)

How are Bad Foils Bad?

1. Stress defects



Nominal
(edge-on)



Break in metal is why!

How are Bad Foils Bad?

2. Nonstress defects



Nominal
(edge-on)

Break, filled



Corrosion



Break in metal is why!

Agenda



12/3/2018

1 PM

JRO 1/2

- **Opacity in HED Astrophysics**
- **HED Opacity Experiments**
- **Bad Foils in Opacity Experiments**
- **Bad Foils in Simulated Opacity Experiments**
 - Radiation Hydrodynamics
 - Synthetic Spectra



Cassio Simulation Scope

- Transport methods
 - Sn
 - IMC
- Source models
 - Fast
 - Slow
- Preheat models
 - No preheat
 - Preheat
- Defect models
 - Stress
 - Nonstress

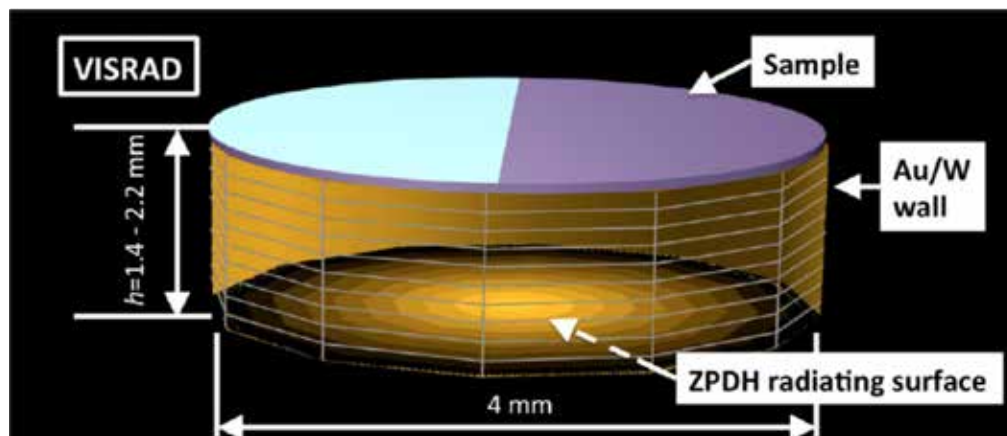
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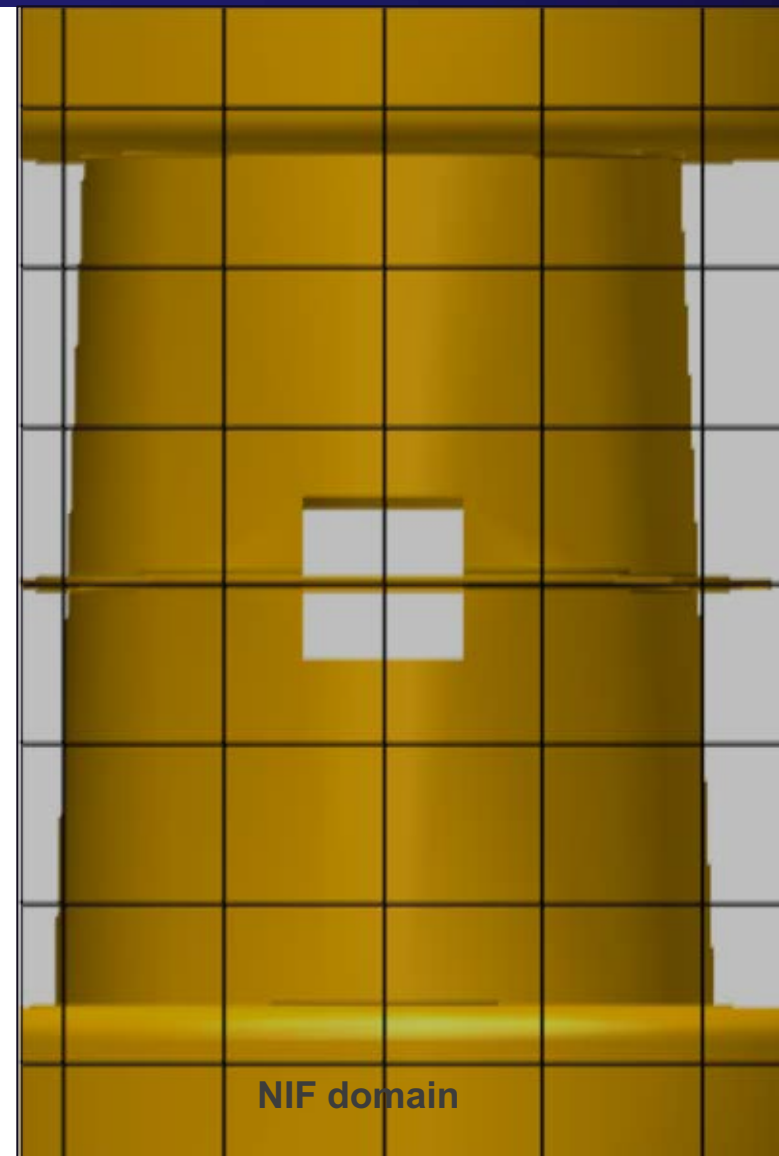
Representative, NOT exhaustive exploration

Cassio Simulation Domain

T. Nagayama et al. (2014)



Z domain

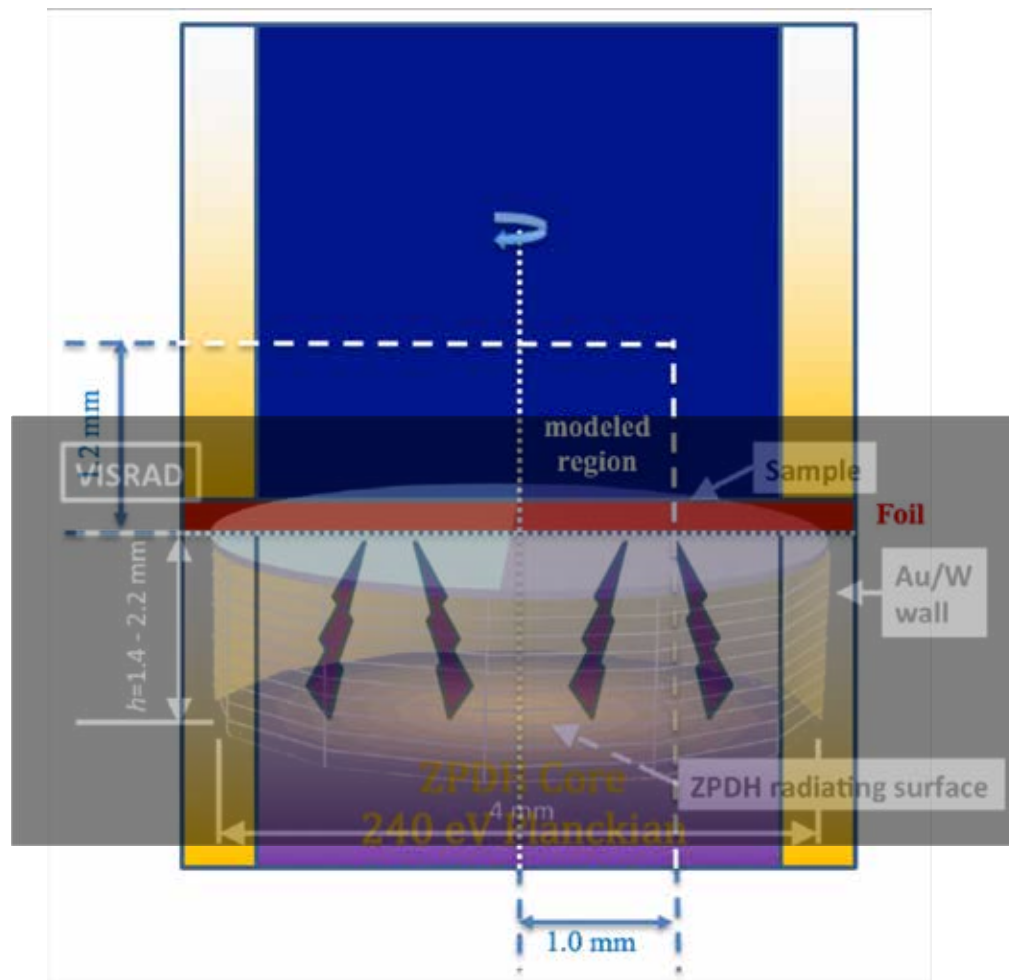


NIF domain

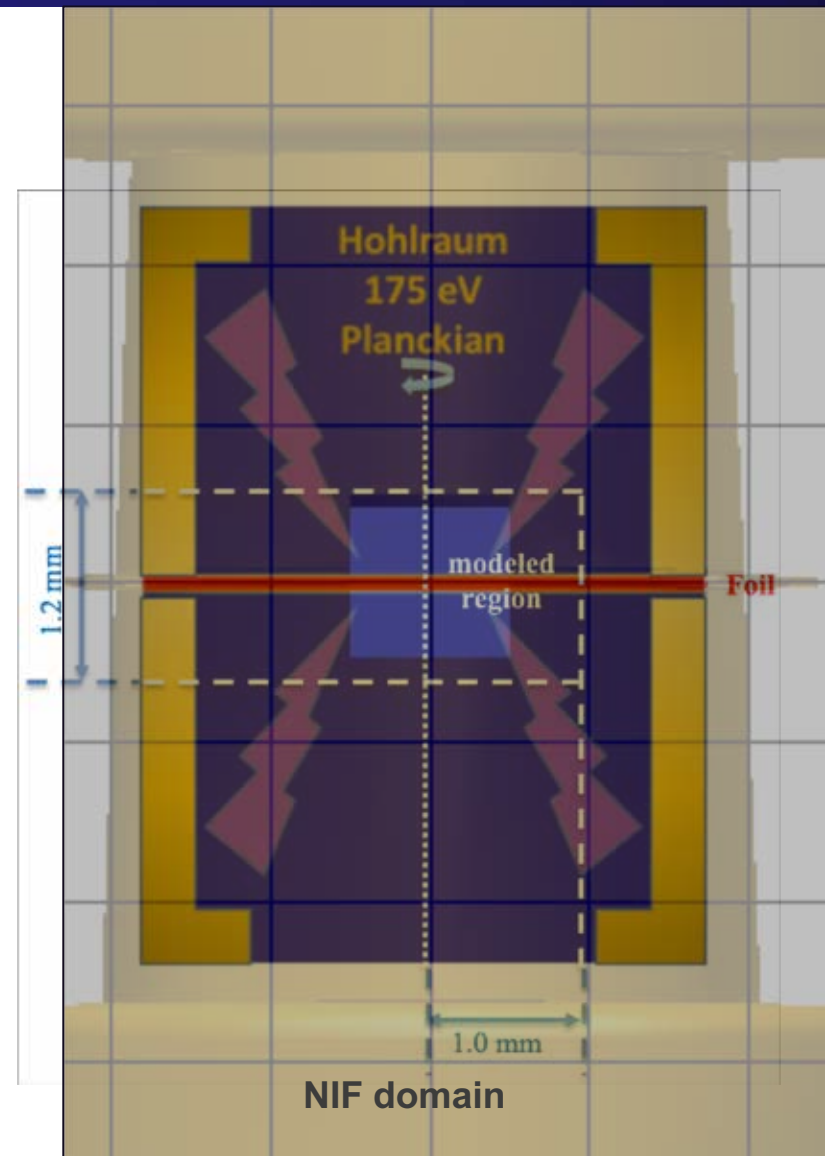
Image: R. Heeter

Cassio Simulation Domain

T. Nagayama et al. (2014)



Z domain

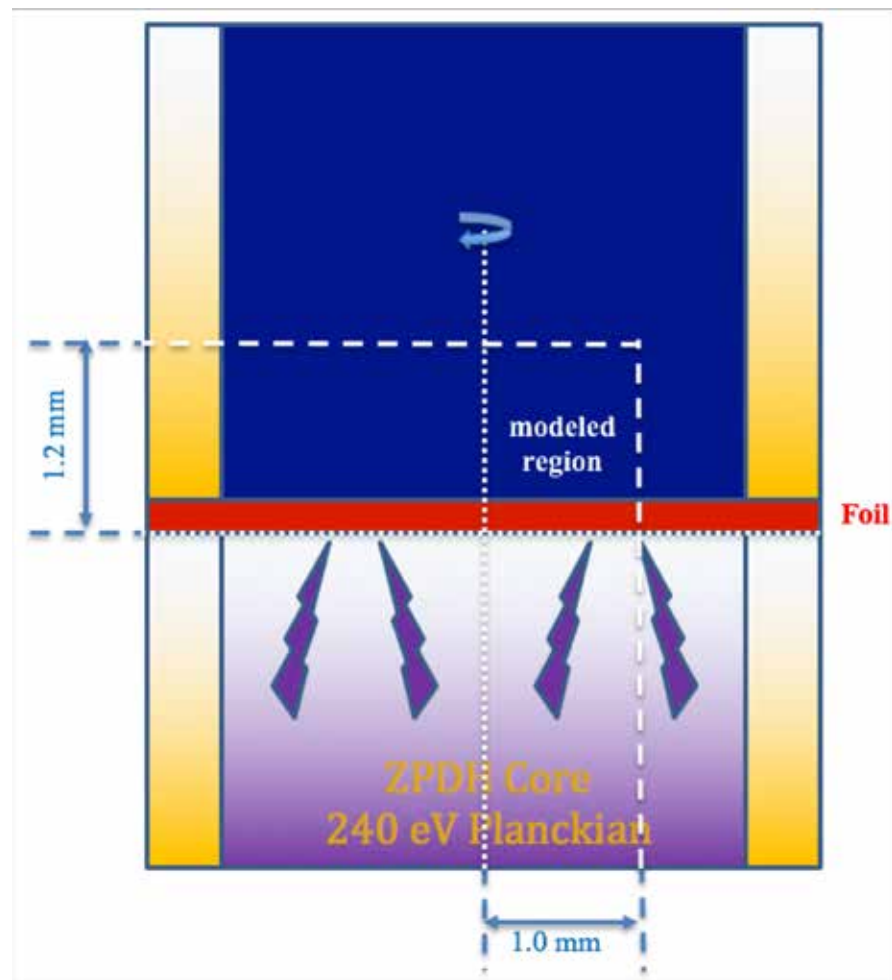


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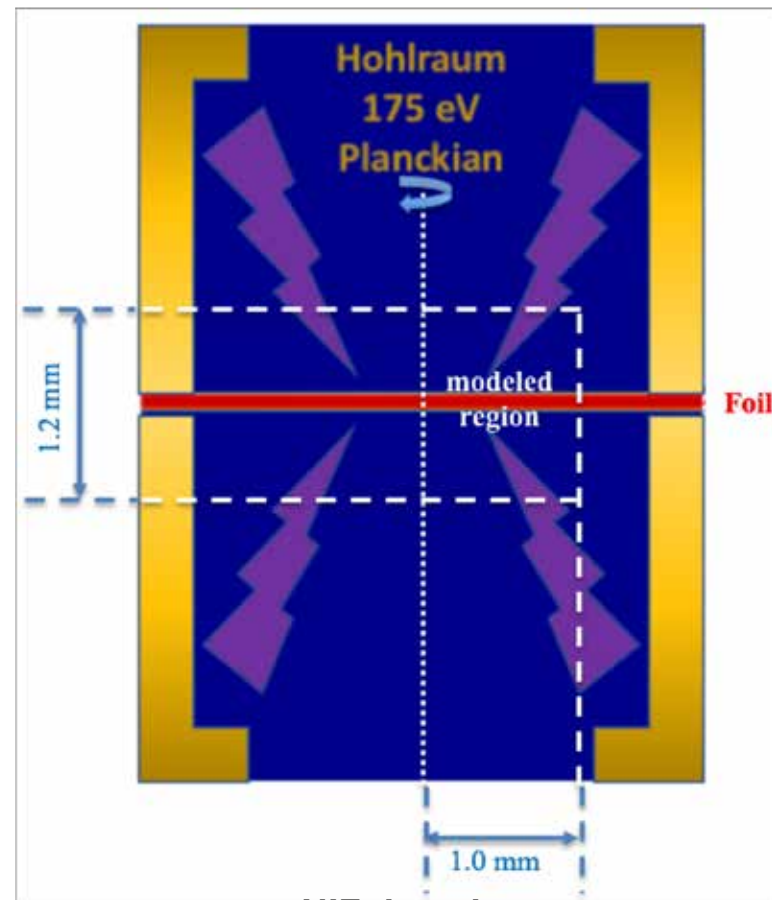
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Cassio Simulation Domain

T. Nagayama et al. (2014)



Z domain

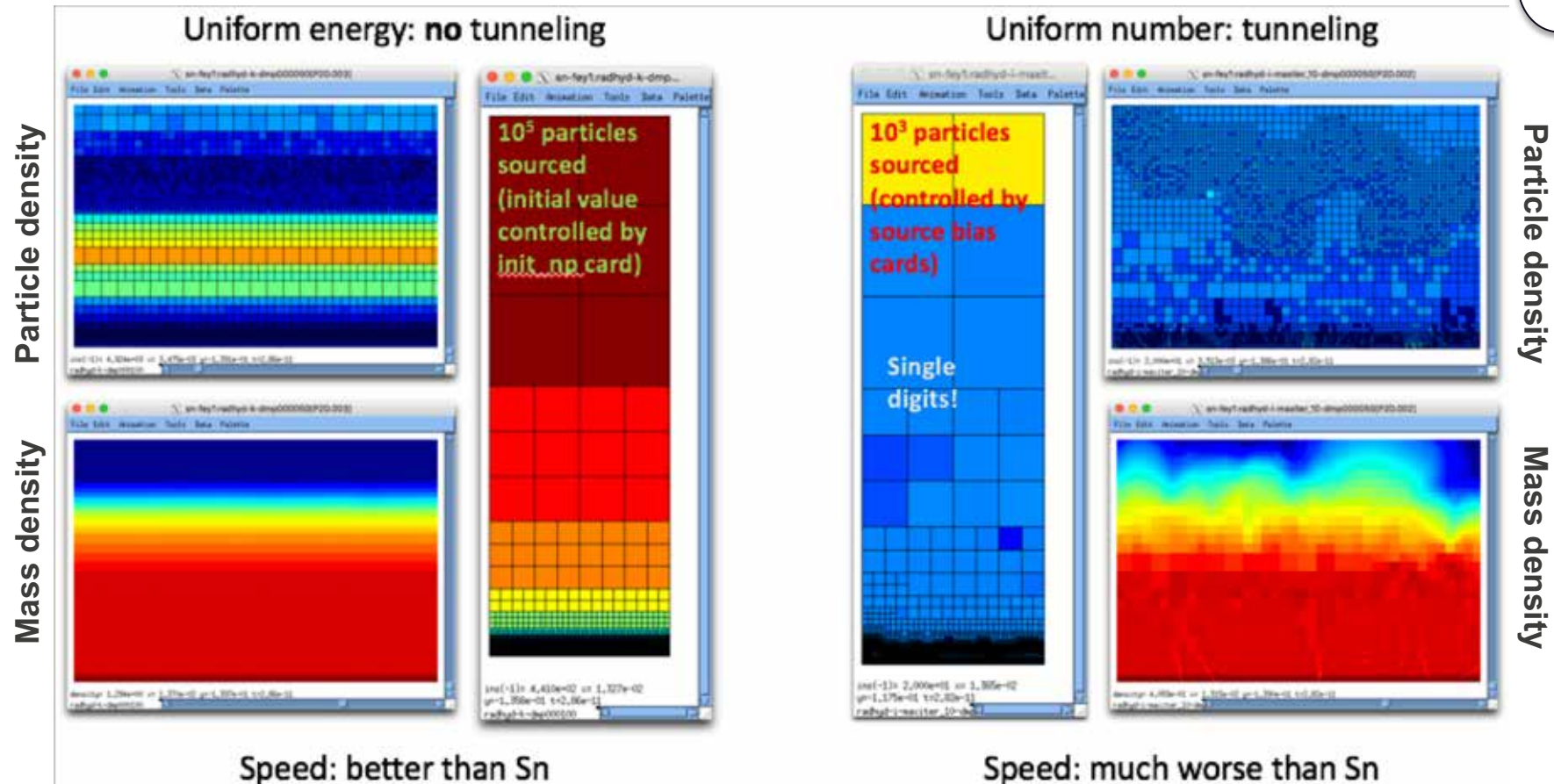


NIF domain

Image: R. Heeter

Results

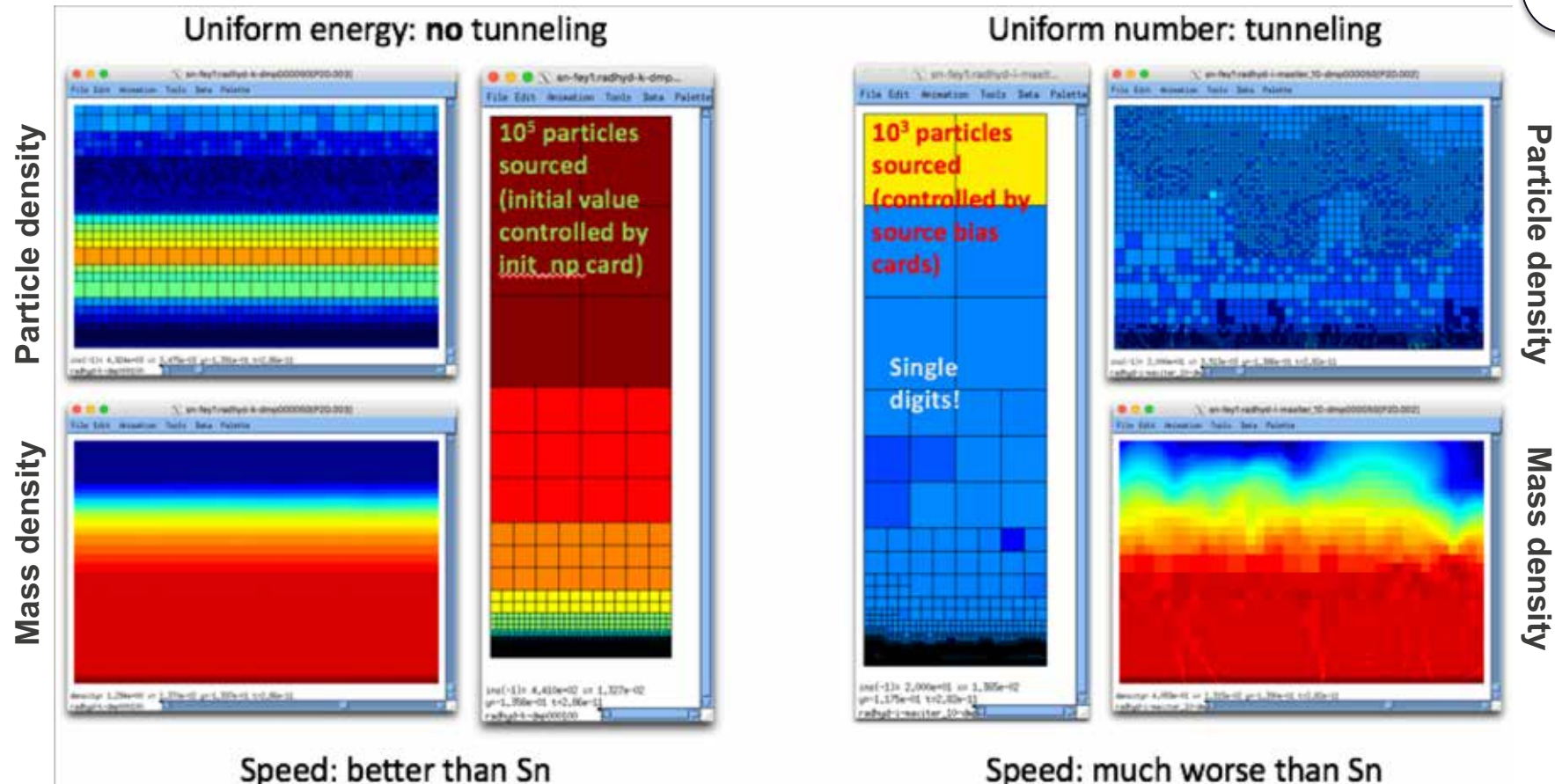
Comparison of transport methods



Base model:
Sn, nominal,
no preheat,
fast source

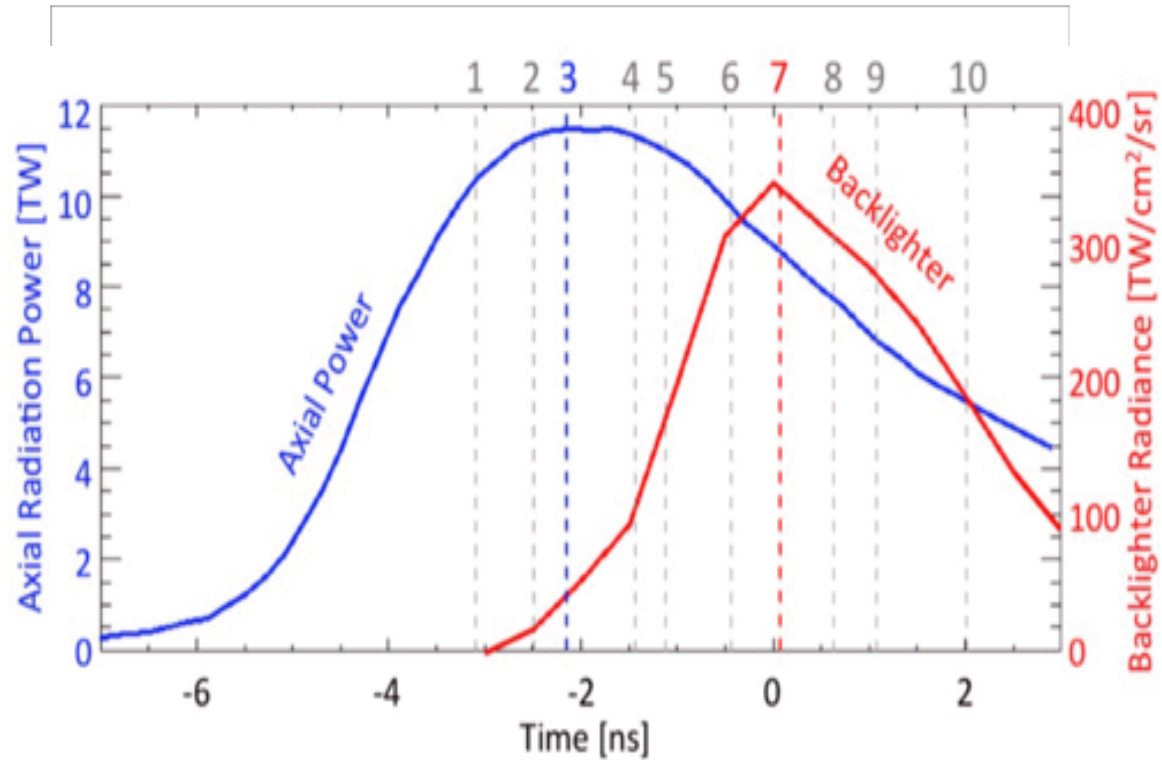
Results

Comparison of transport methods

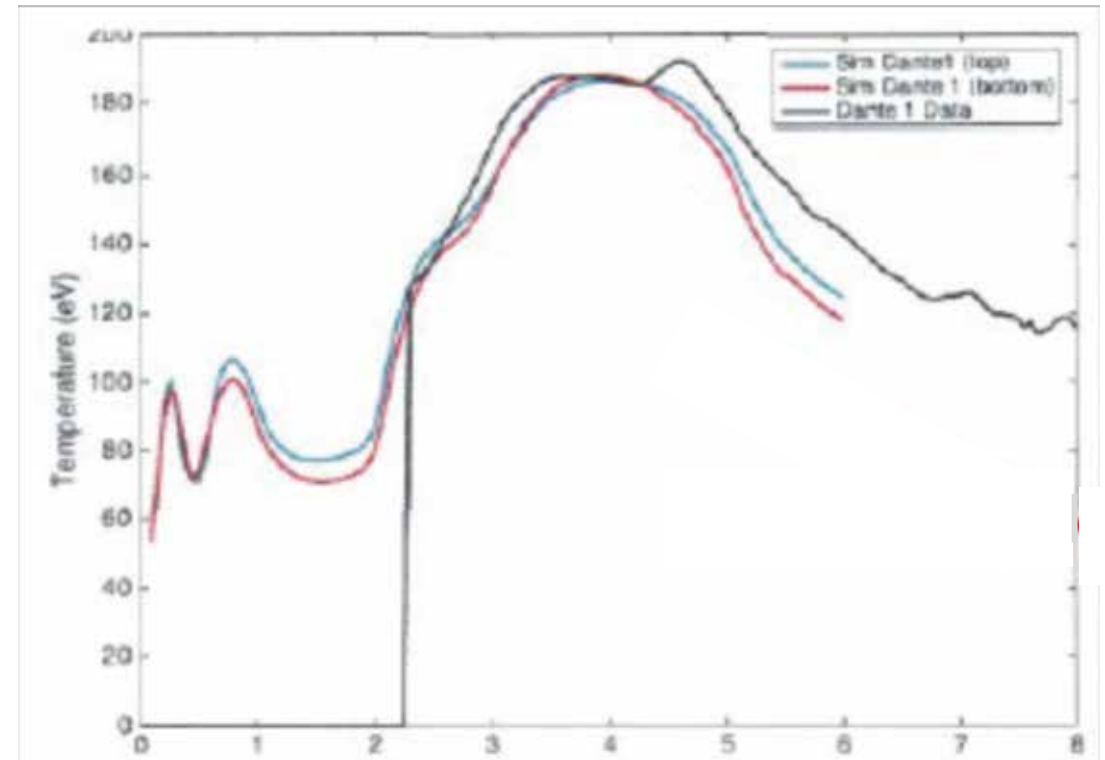


Base model:
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fast source

Source & Preheat

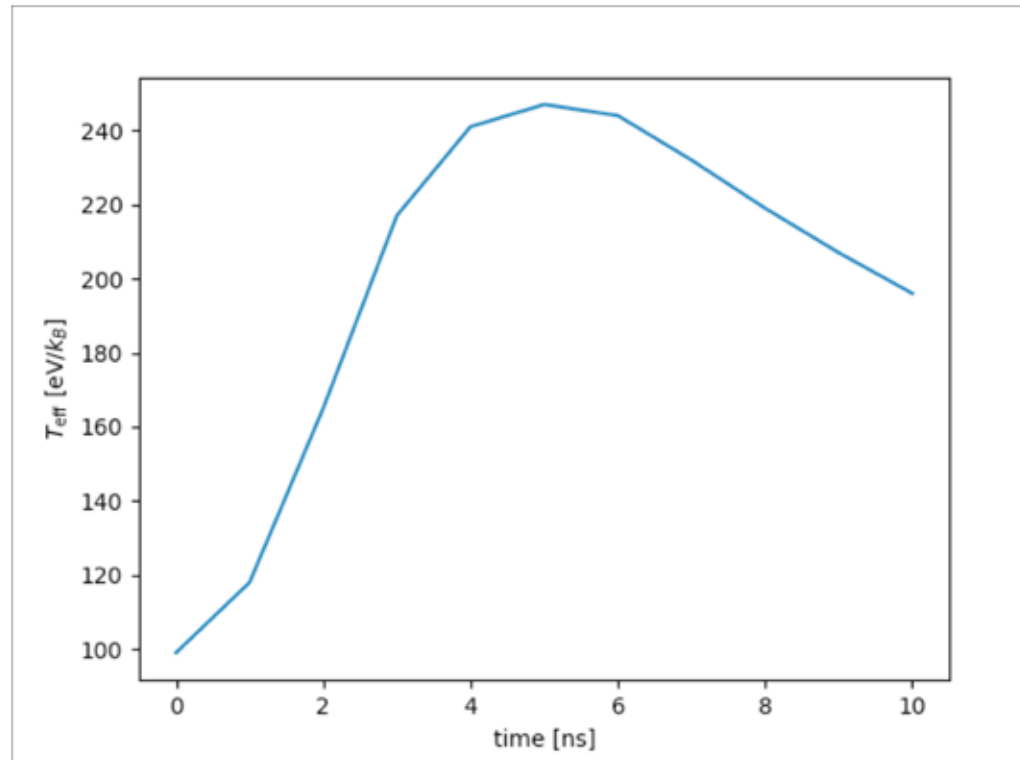


Z source wall temperature
T. Nagayama et al. (2016)

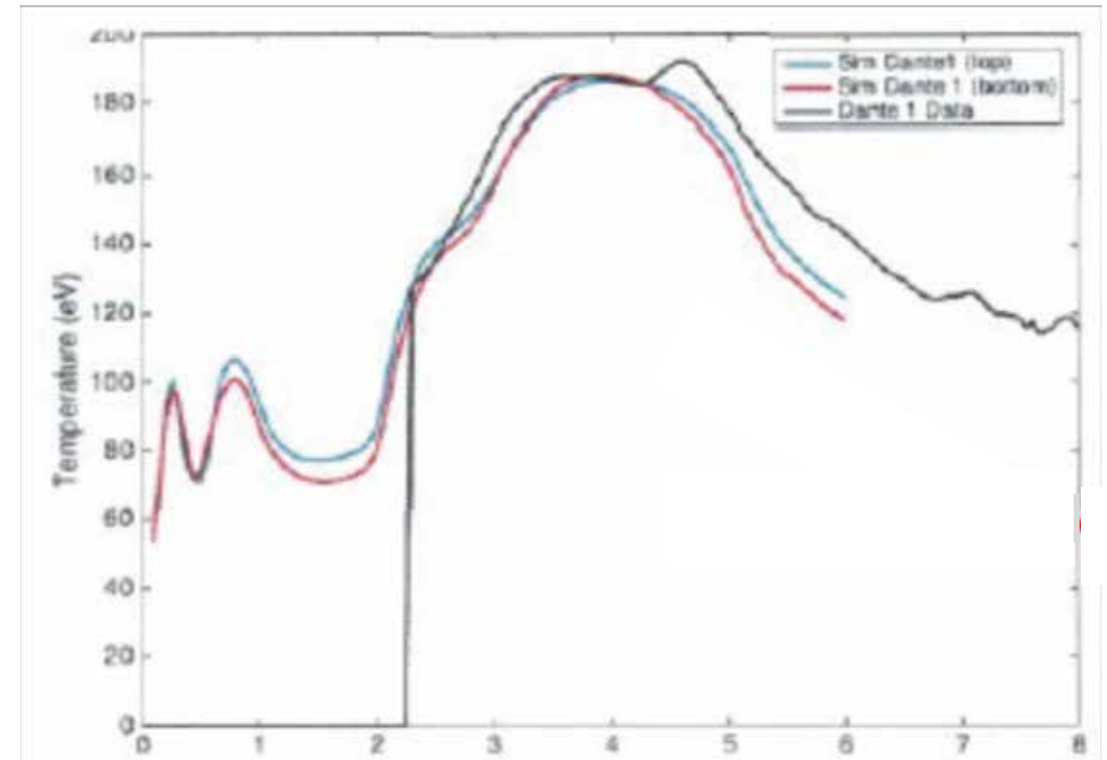


NIF source wall temperature
T.S. Perry et al. (2018)

Source & Preheat

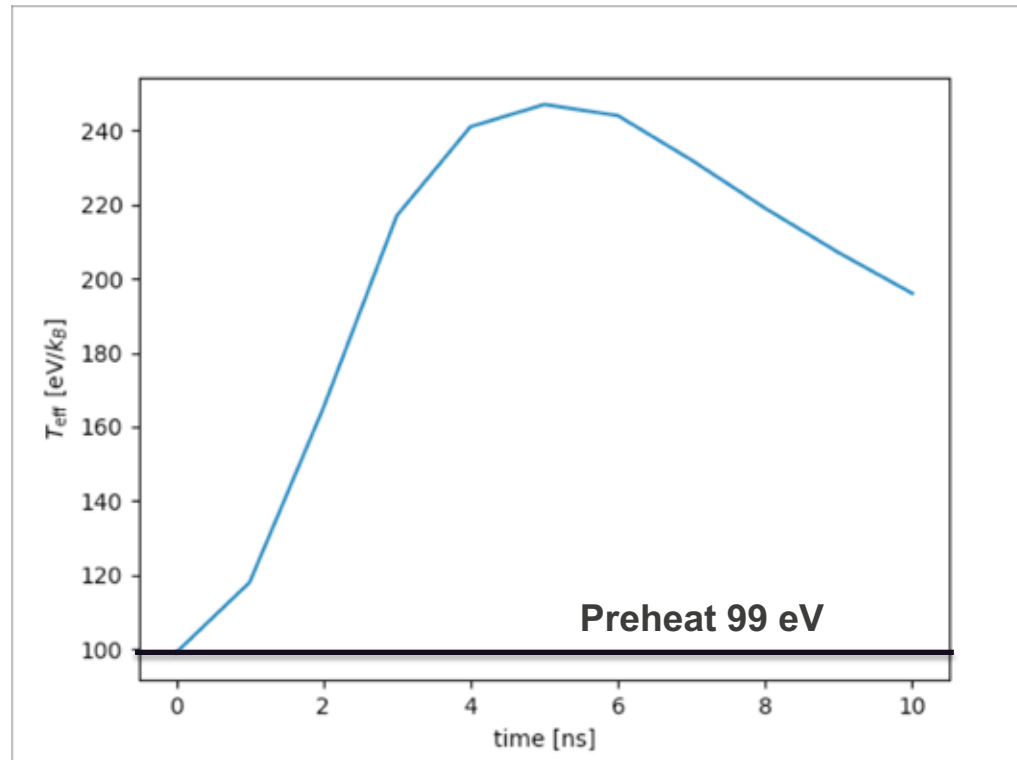


Z source wall temperature
T. Nagayama et al. (2016)

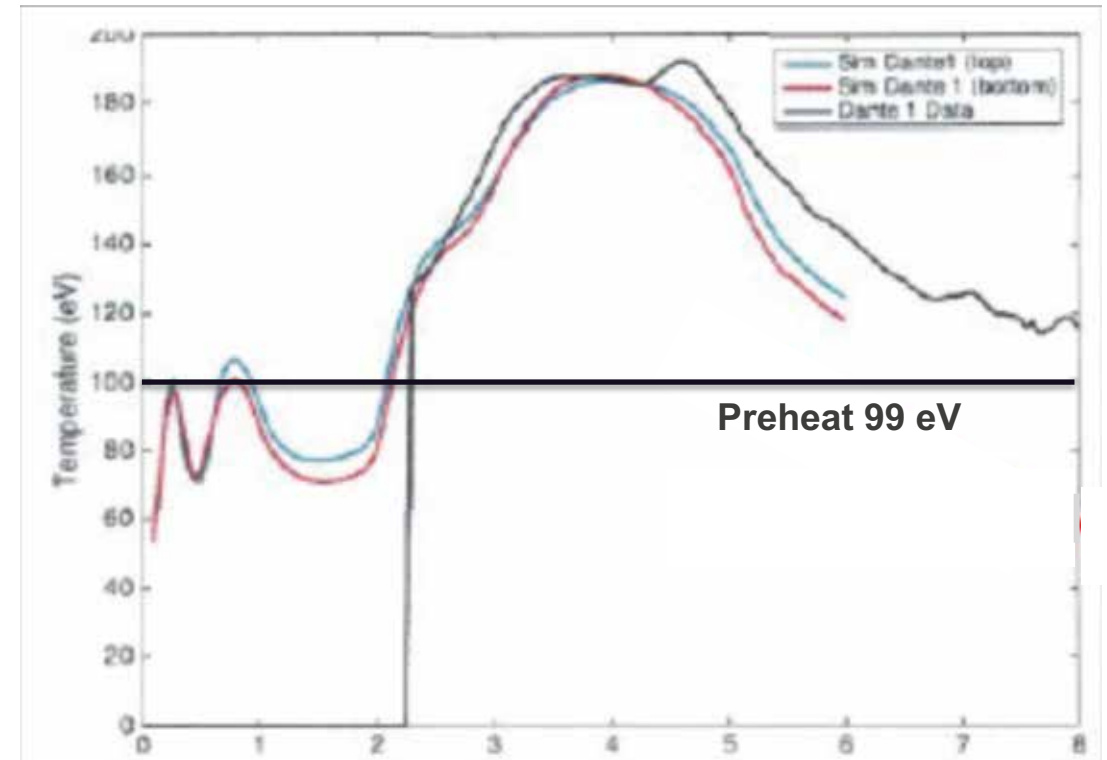


NIF source wall temperature
T.S. Perry et al. (2018)

Source & Preheat

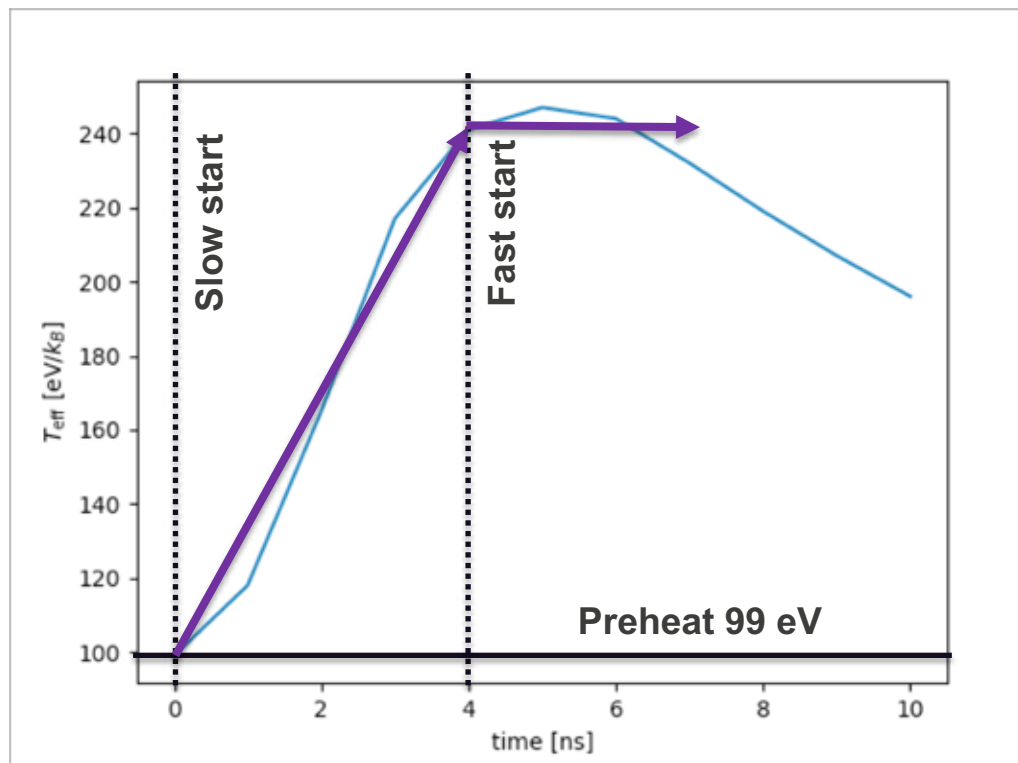


Z source wall temperature
T. Nagayama et al. (2016)

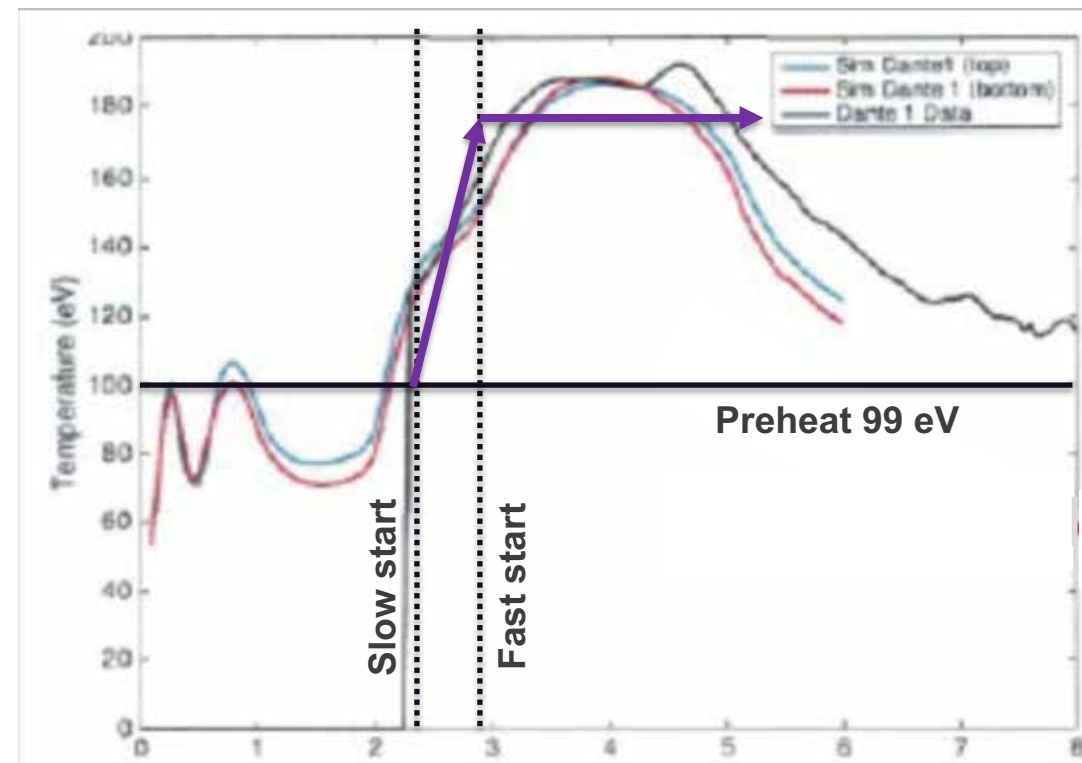


NIF source wall temperature
T.S. Perry et al. (2018)

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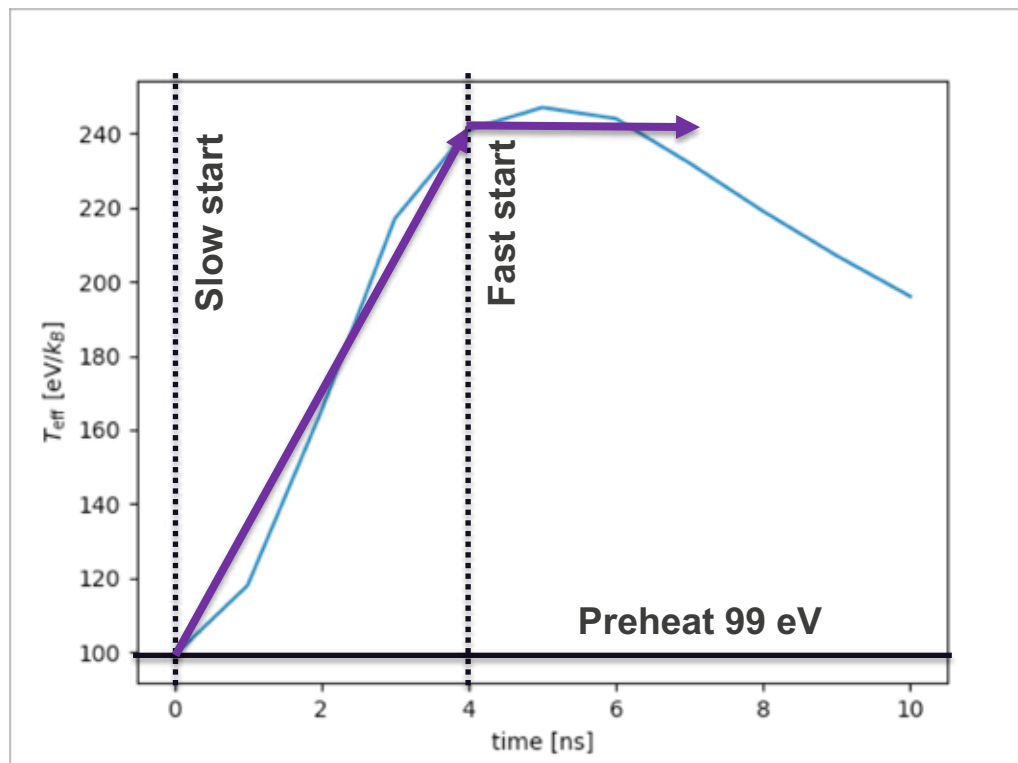


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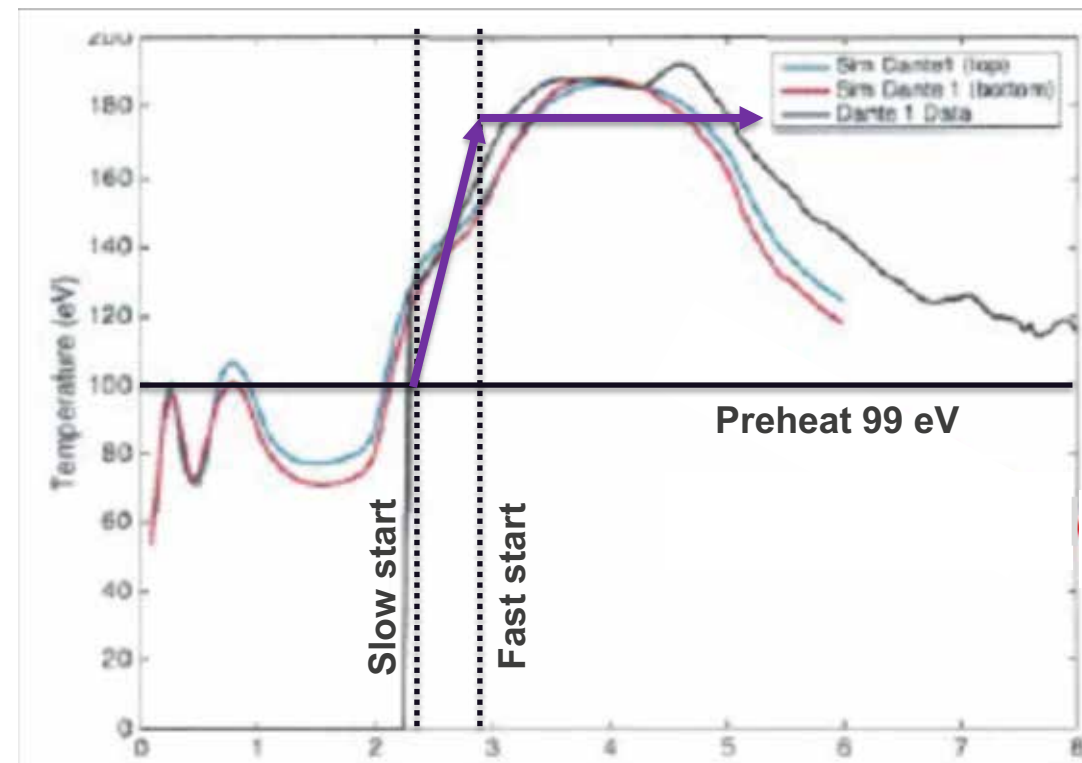


NIF source wall temperature
T.S. Perry et al. (2018)

Source & Preheat



Z source wall temperature
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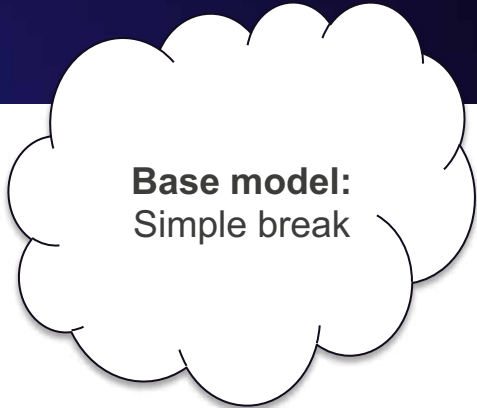


NIF source wall temperature
T.S. Perry et al. (2018)

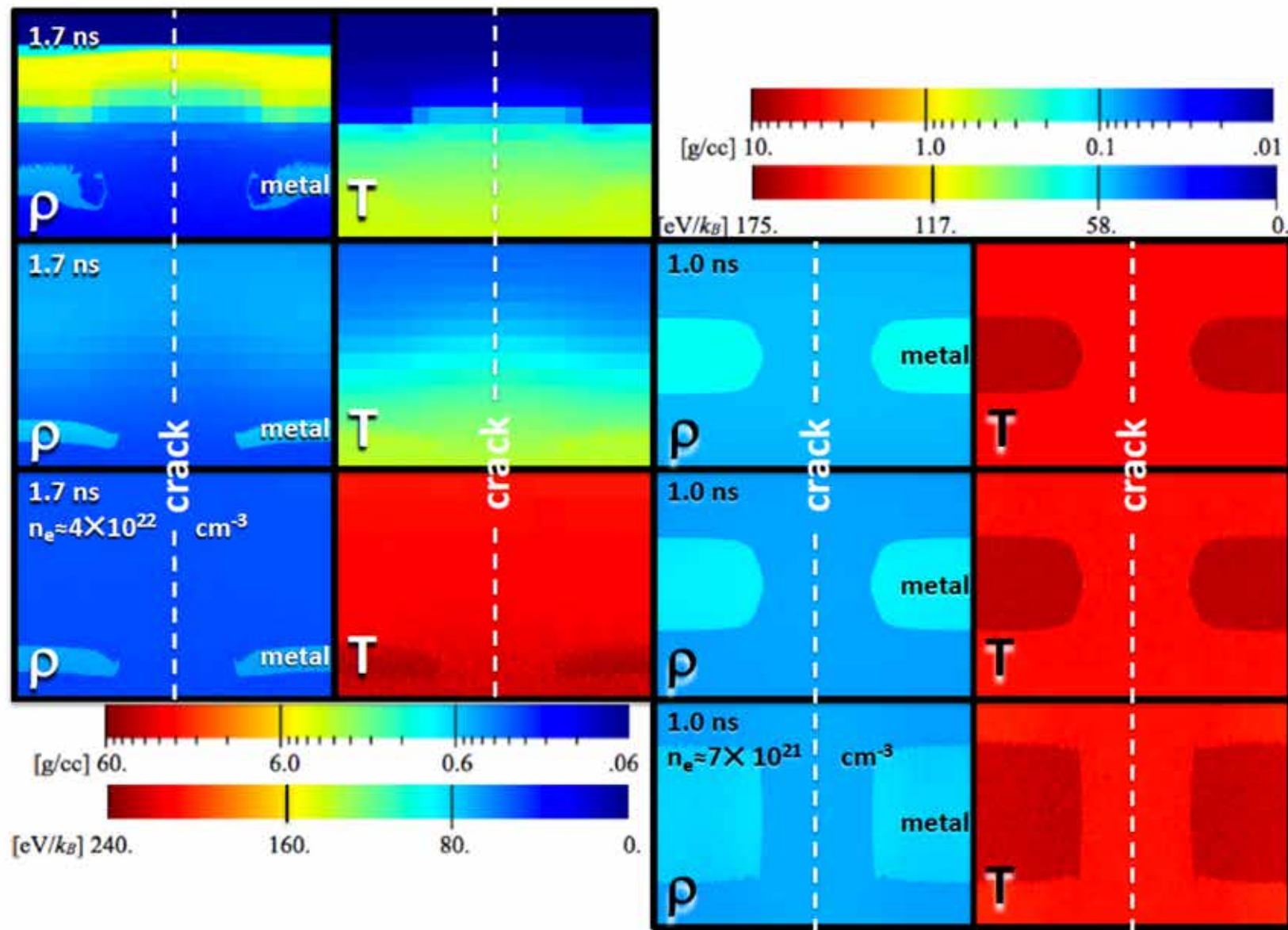
Simplified and uniform models

Results

Comparison of preheat X source models



Base model:
Simple break



No Preheat
Slow Ramp

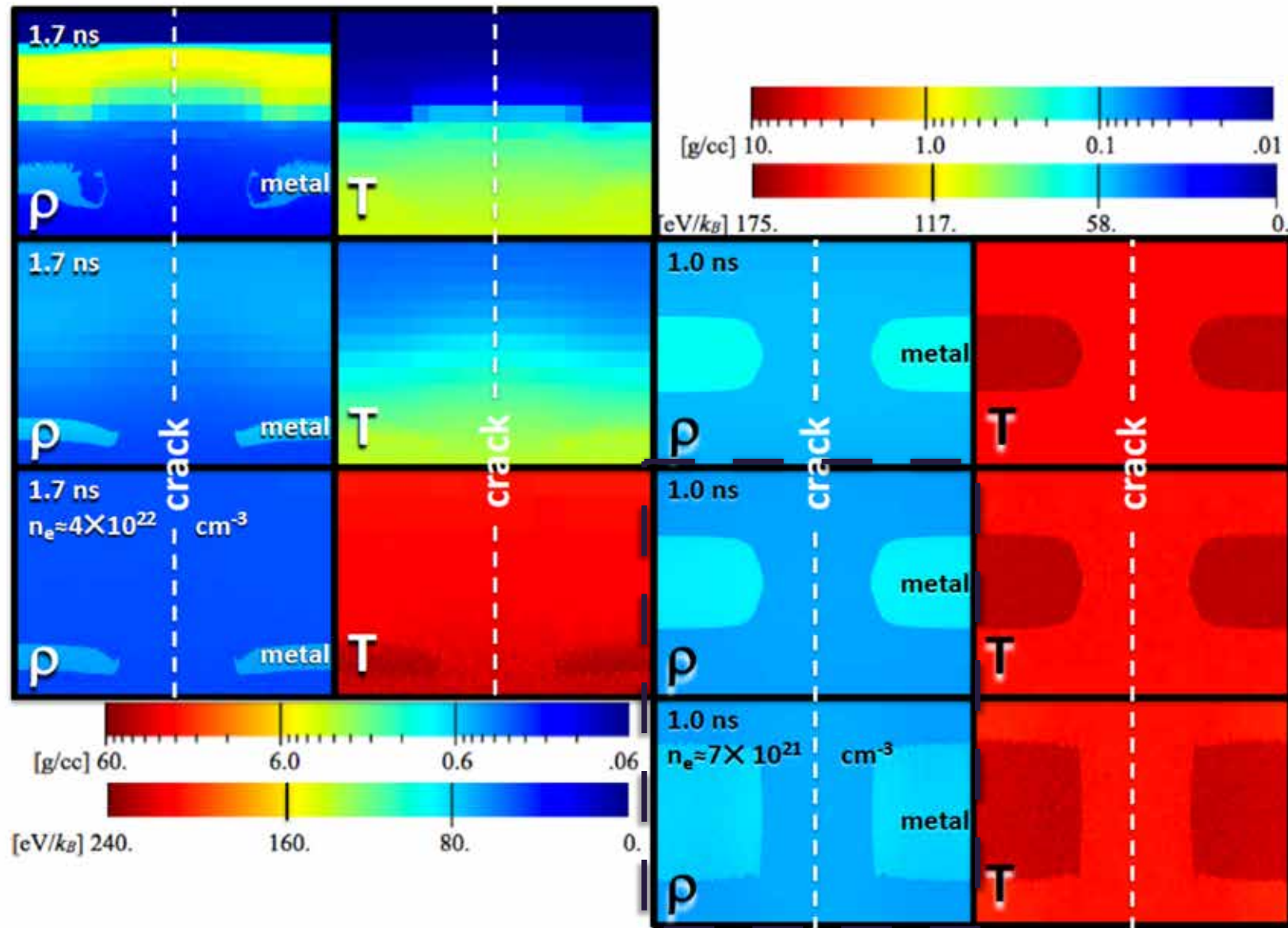
99 eV Preheat
Slow Ramp

99 eV Preheat
Fast Ramp

No Preheat
Fast Ramp

Z

NIF



No Preheat
Slow Ramp

99 eV Preheat
Slow Ramp

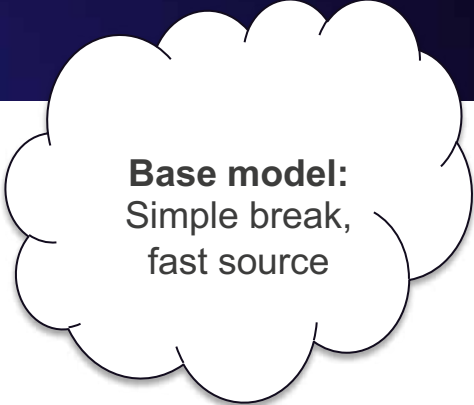
99 eV Preheat
Fast Ramp

No Preheat
Fast Ramp

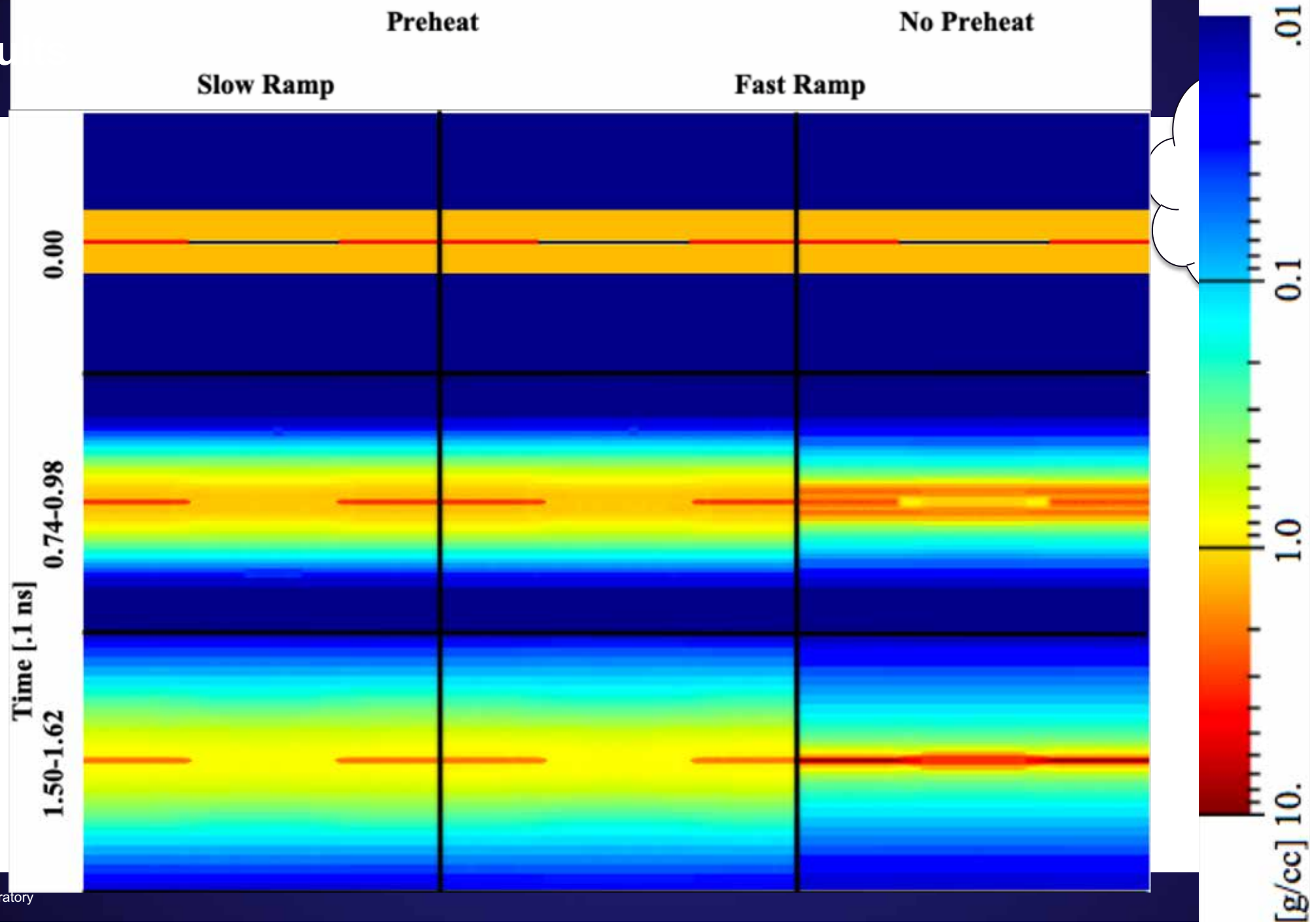
Preheat explains the greatest variation between models: overexpansion AND corrugation when absent

Results

Comparison of preheat models

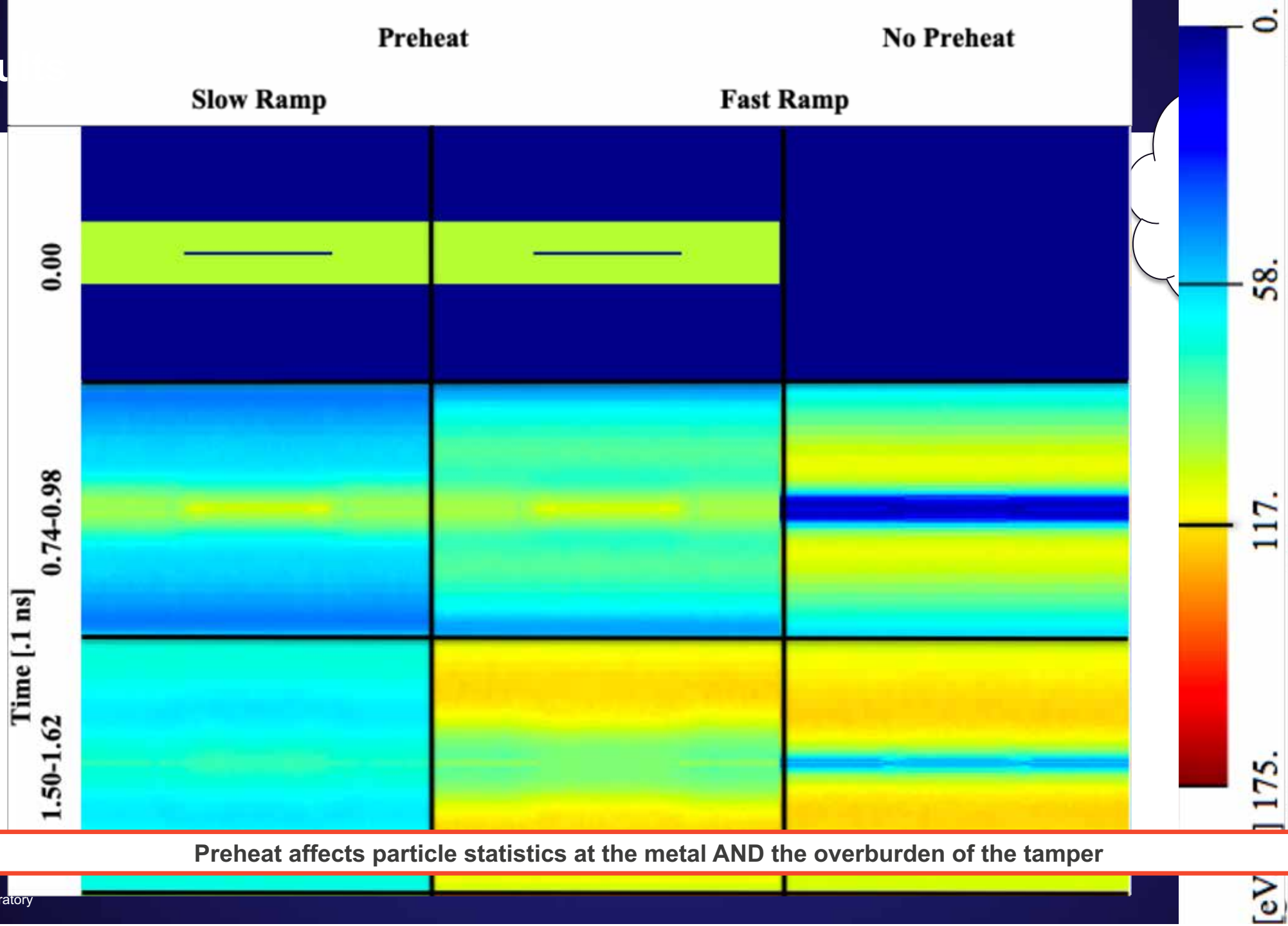


Base model:
Simple break,
fast source



Model:
break,
source

Resu

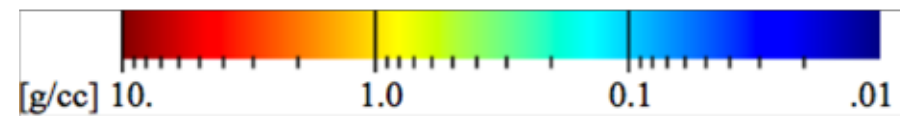


Preheat affects particle statistics at the metal AND the overburden of the tamper

Results

Comparison of defect models

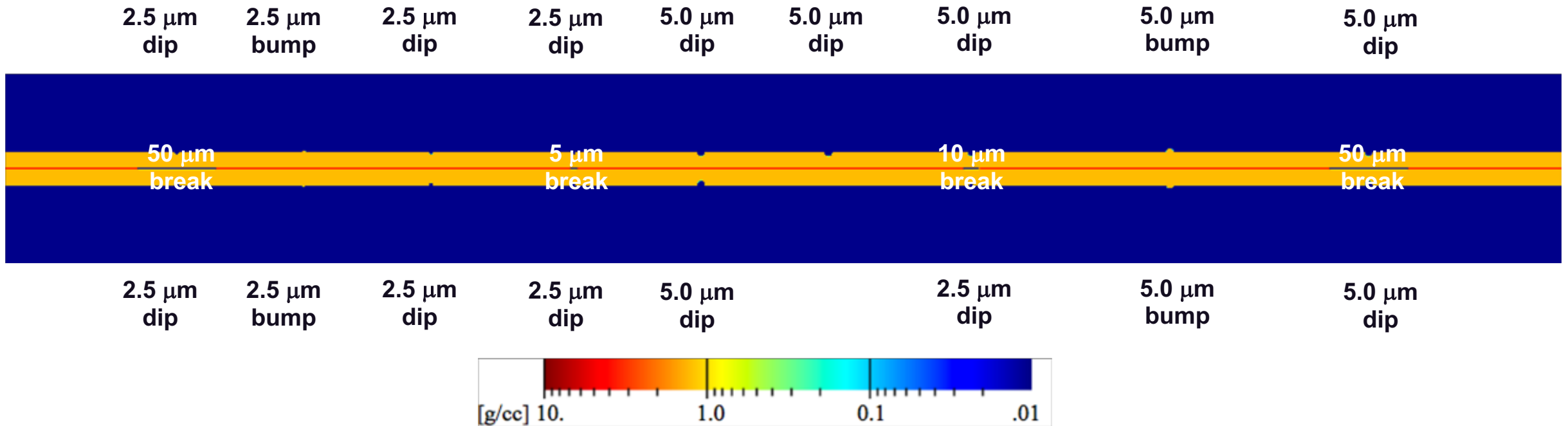
Base model:
Fast source



Results

Comparison of defect models

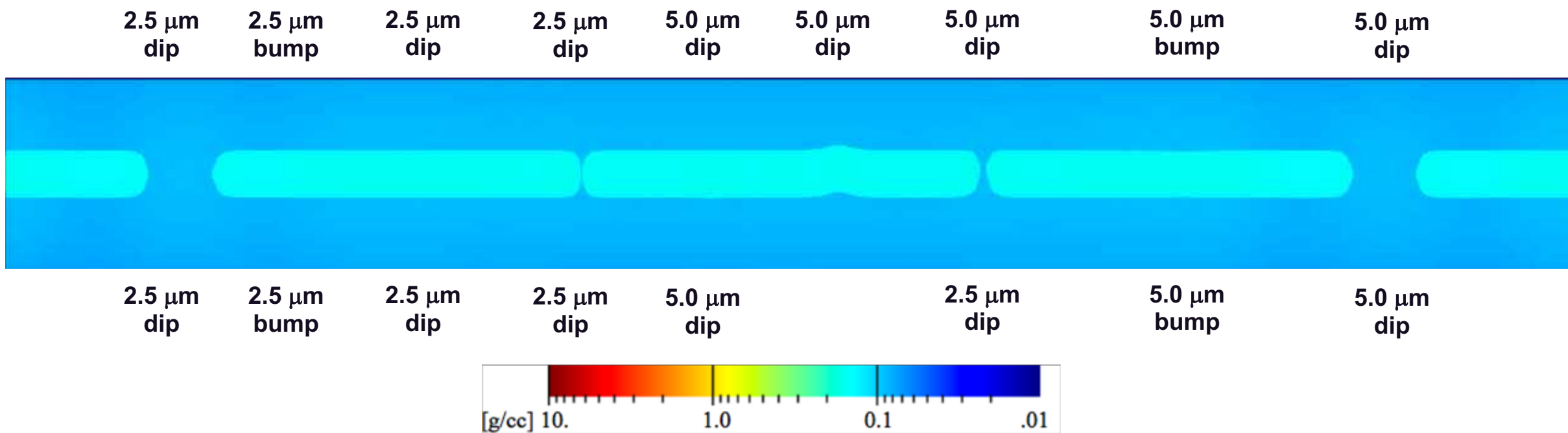
Base model:
Fast source



Results

Comparison of defect models
Preheat

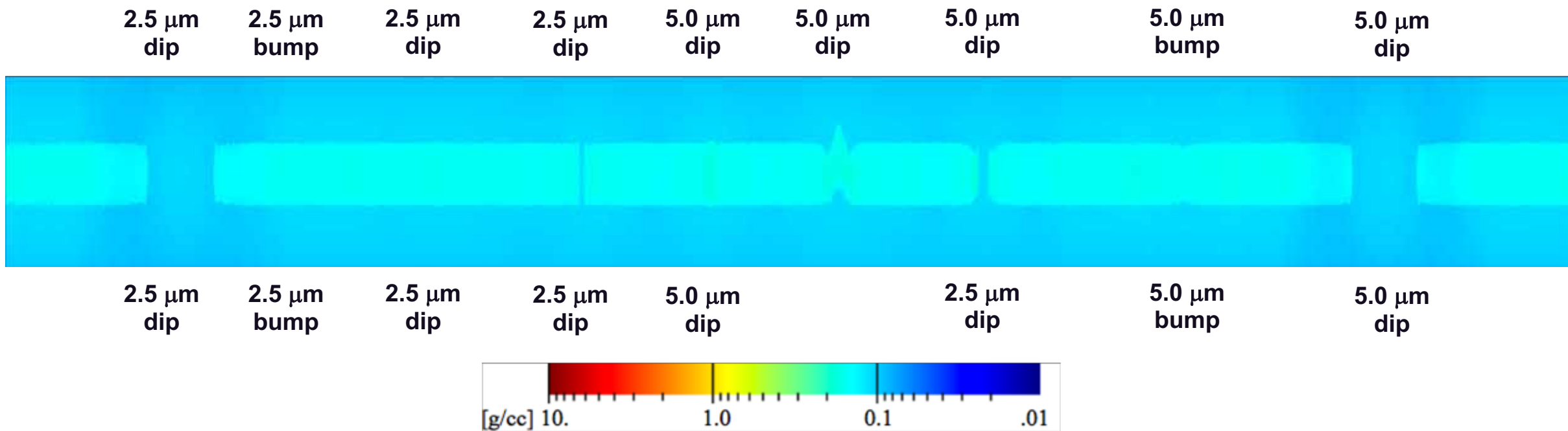
Base model:
Fast source



Results

Comparison of defect models
No preheat

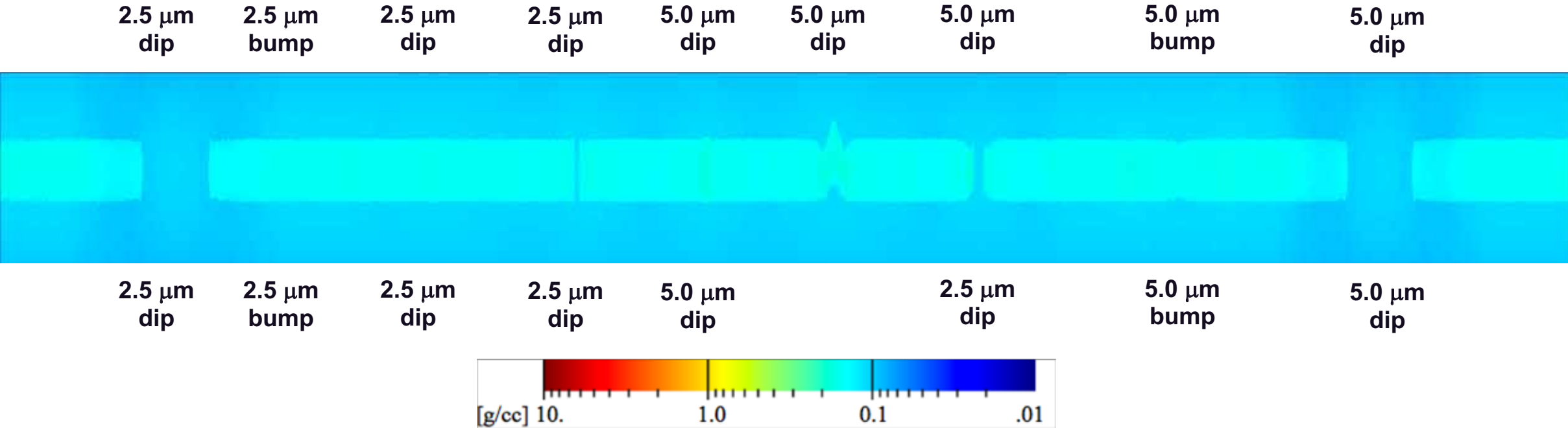
Base model:
Fast source



Results

Comparison of defect models
No preheat

Base model:
Fast source

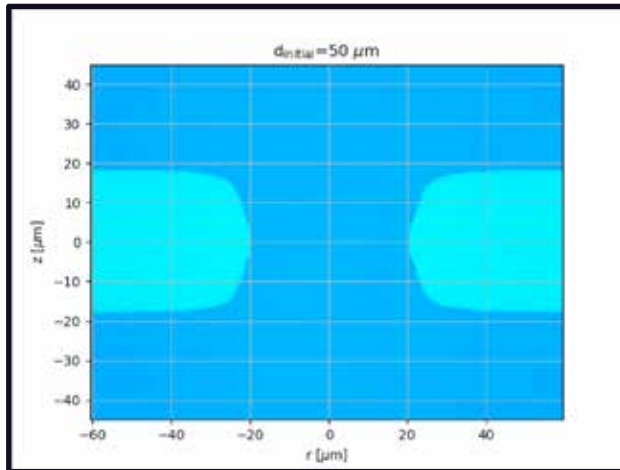


Stress defects in tamper do not break metal

Nonstress defects were unremarkable

Results

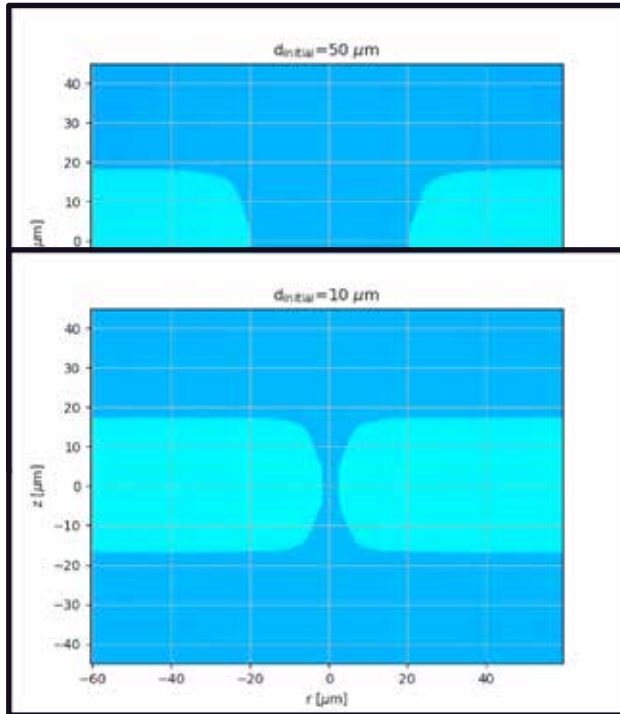
Comparison of defect sizes



Base model:
Simple break

Results

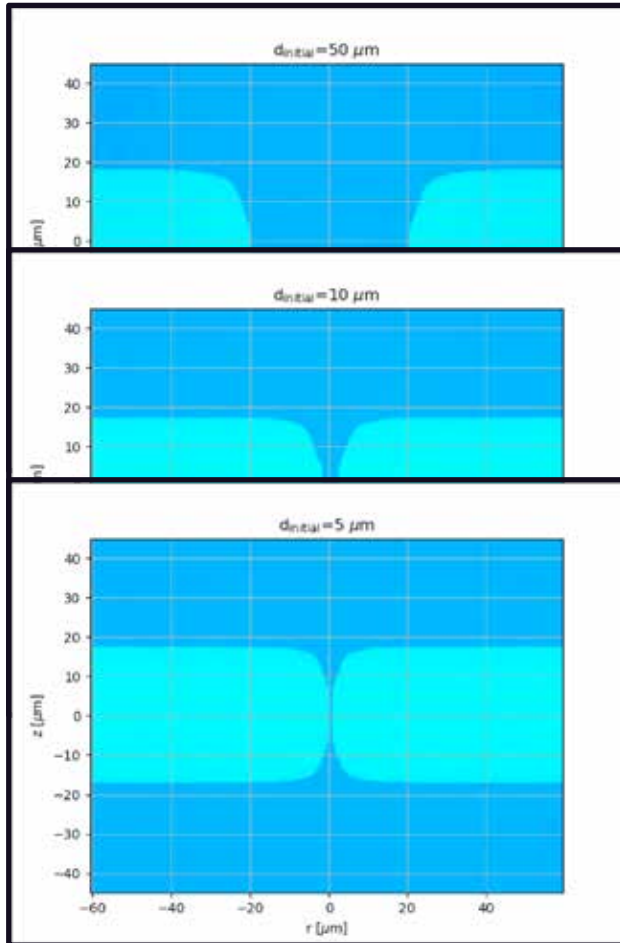
Comparison of defect sizes



Base model:
Simple break

Results

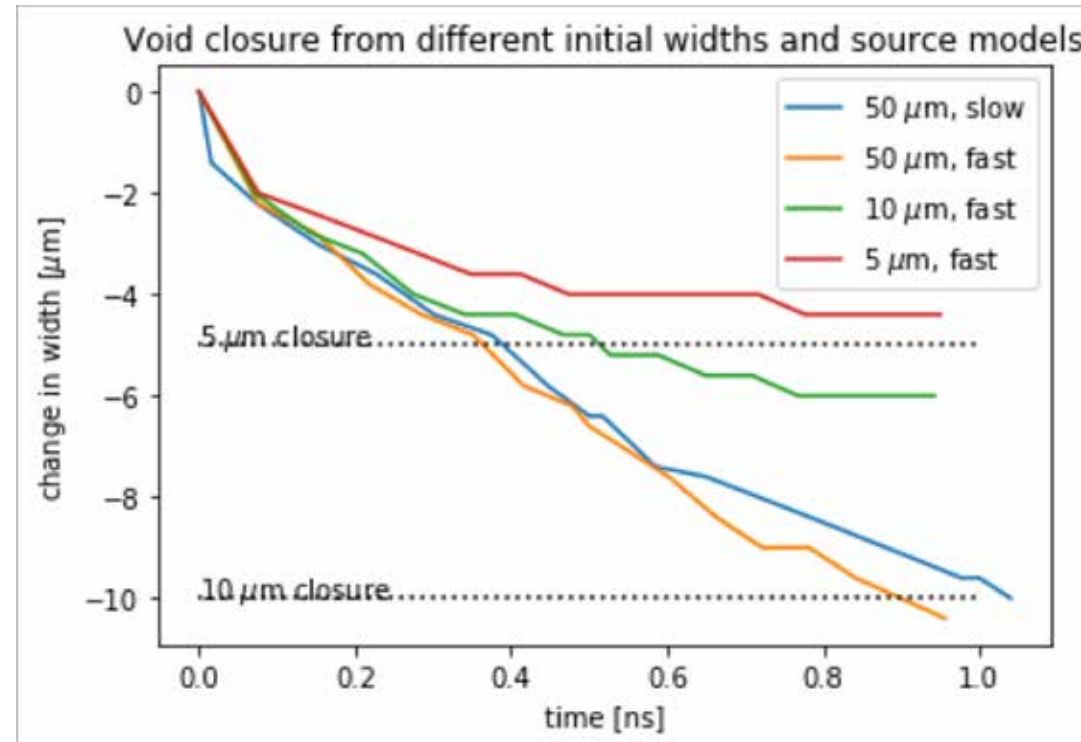
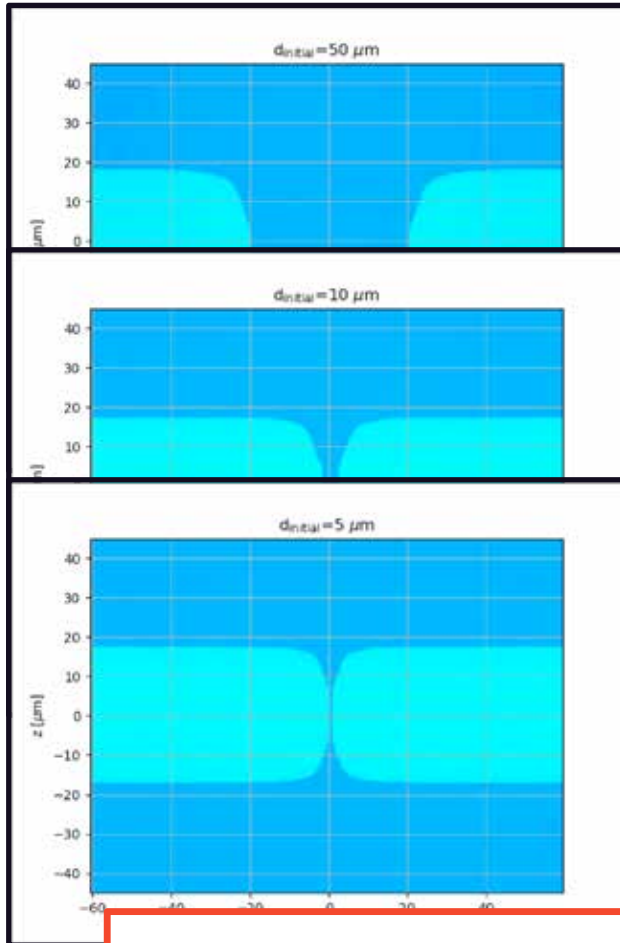
Comparison of defect sizes



Base model:
Simple break

Results

Comparison of defect sizes



Base model:
Simple break

Infill of break by tamper arrests closure by metal

Agenda

12/3/2018

1 PM

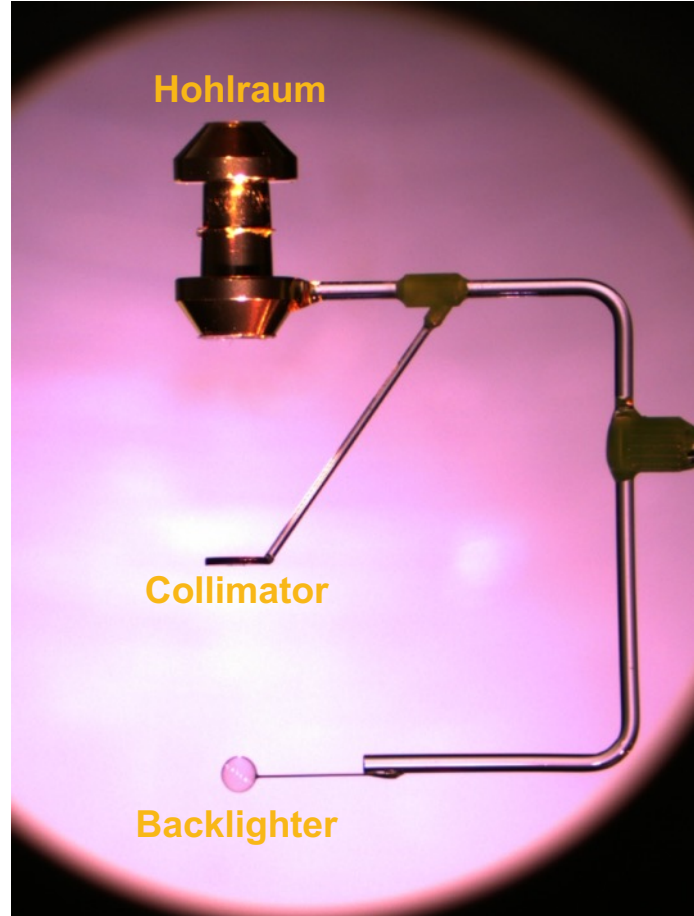
JRO 1/2

- **Opacity in HED Astrophysics**
- **HED Opacity Experiments**
- **Bad Foils in Opacity Experiments**
- **Bad Foils in Simulated Opacity Experiments**
 - Radiation Hydrodynamics
 - Synthetic Spectra



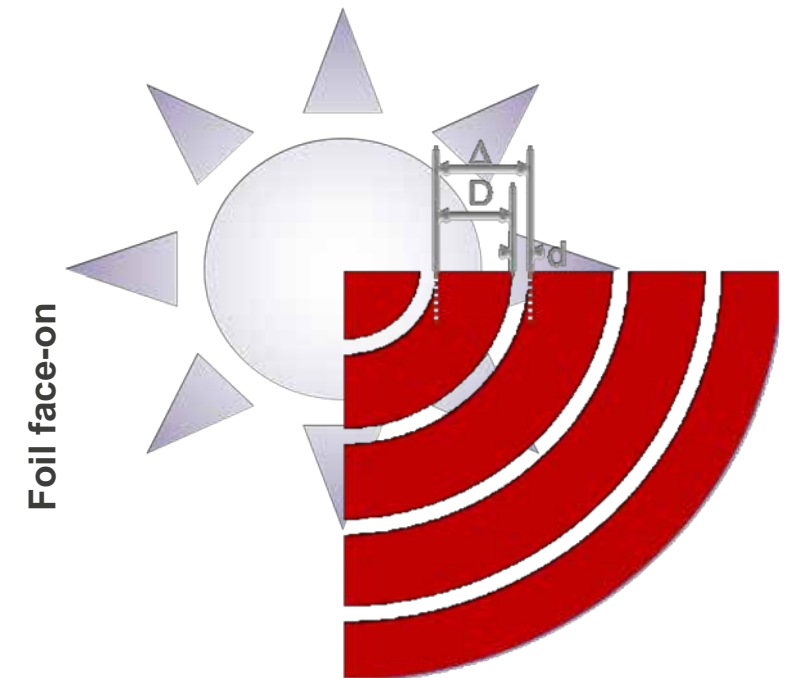
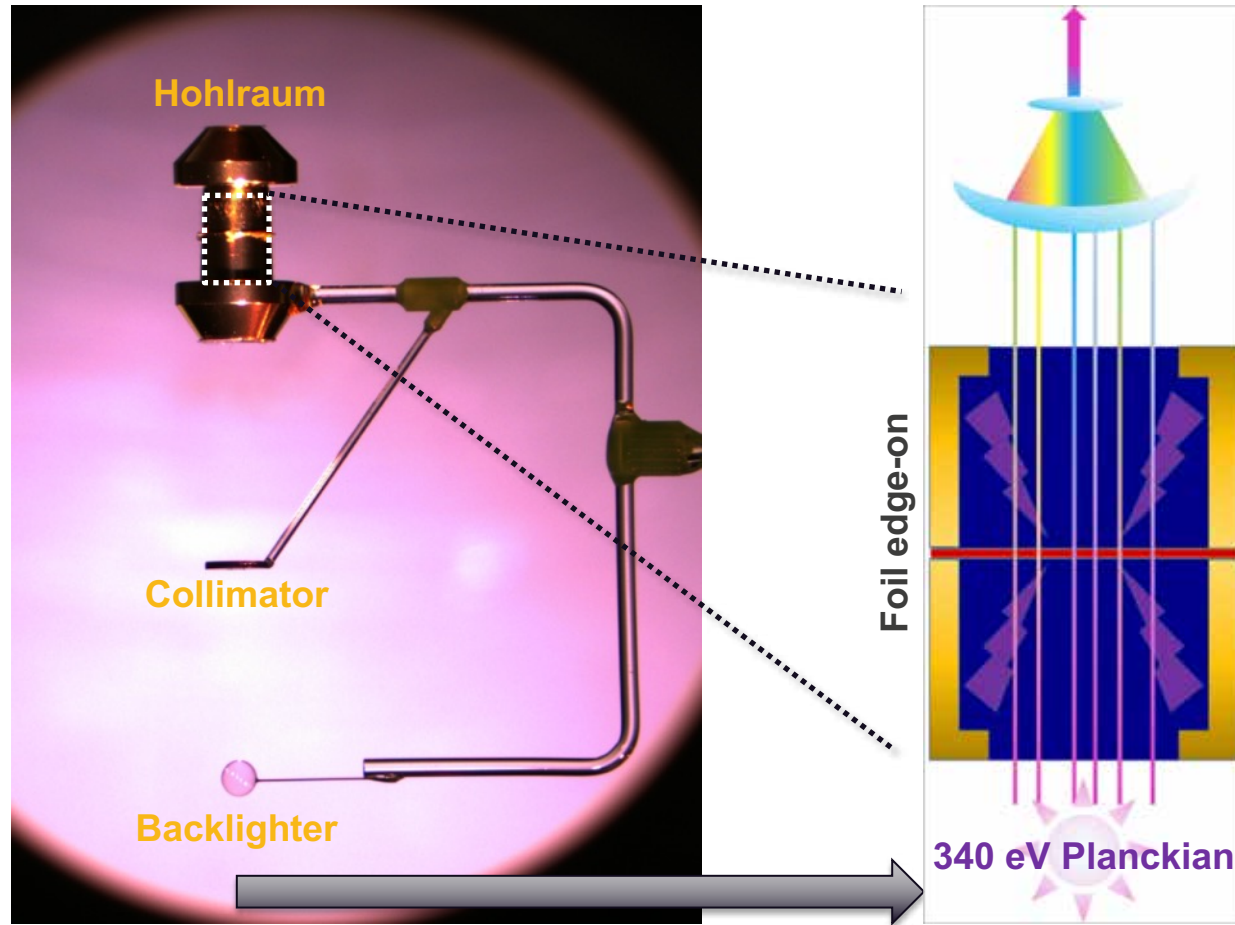
View From Spectrograph

Image: T. Cardenas

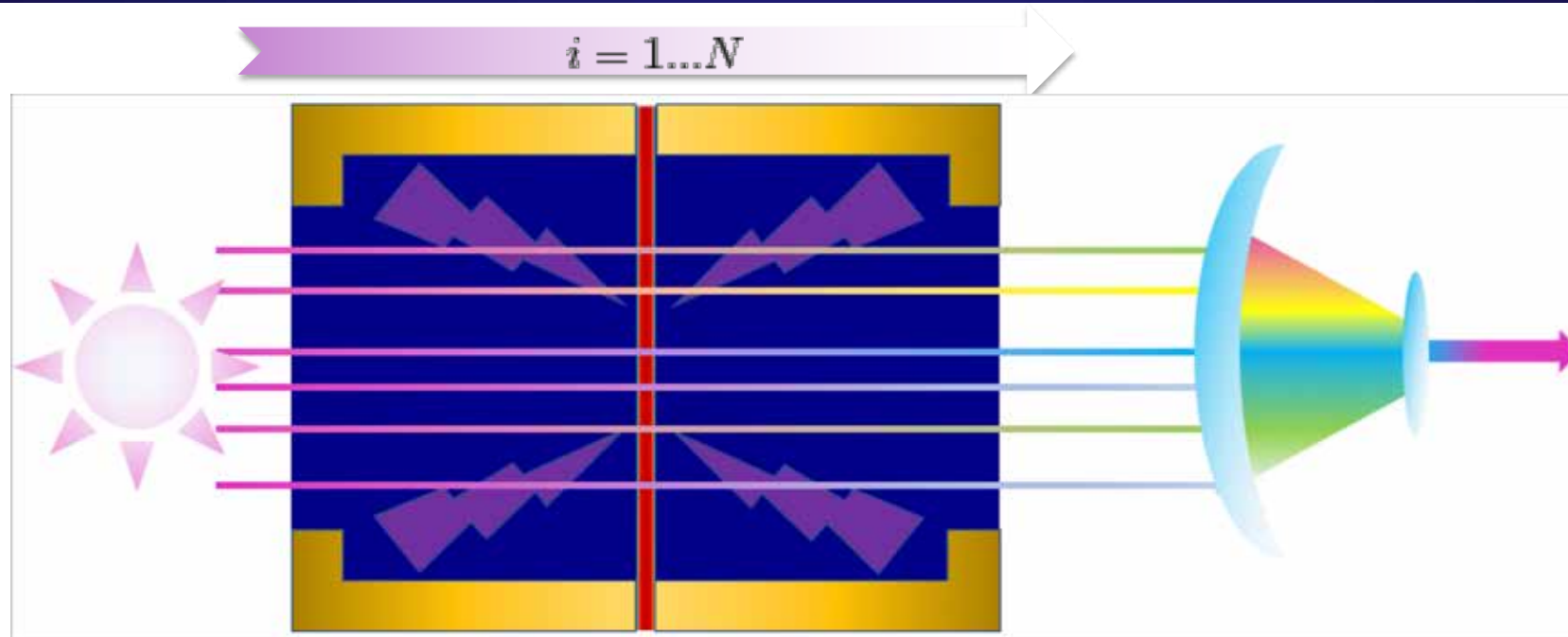


View From Spectrograph

Image: T. Cardenas



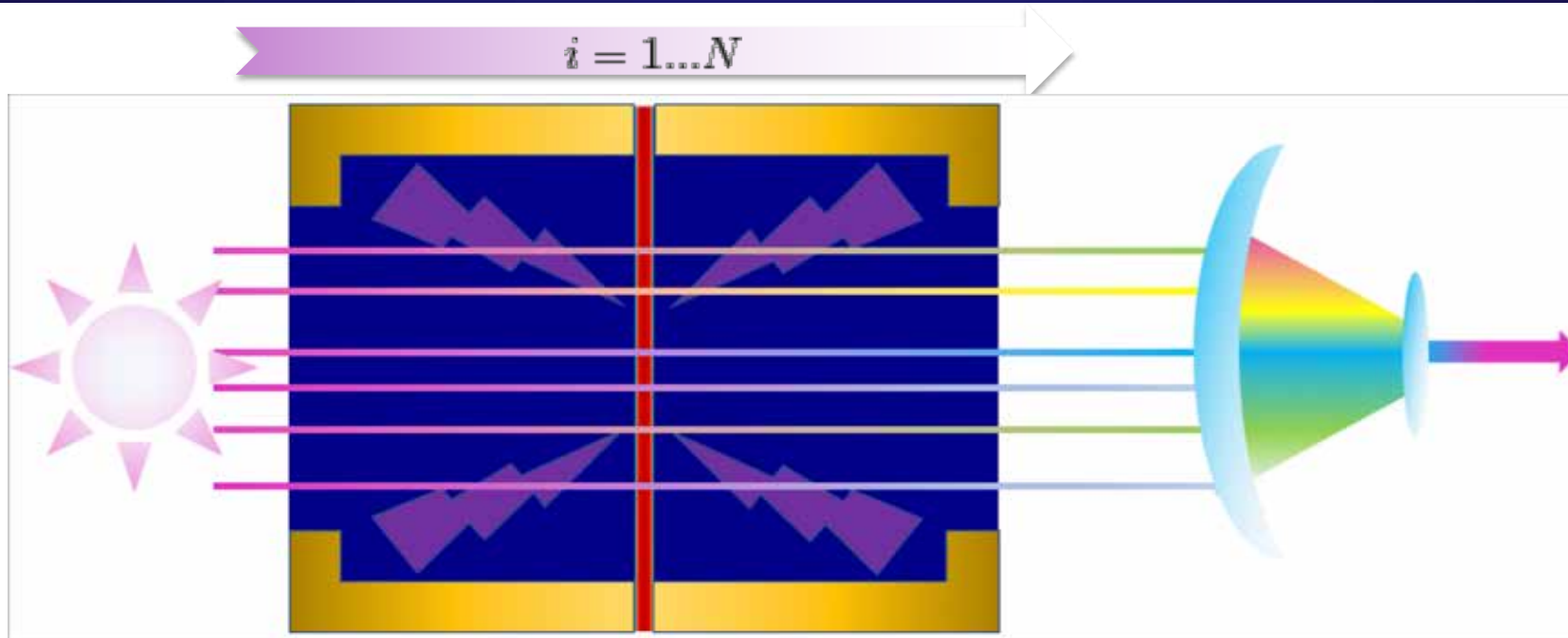
Spectral Synthesis



Equation of radiative transfer

$$I_{\nu,i} = I_{\nu,i-1}e^{-\delta\tau_{\nu,i}} + S_{\nu,i}(1 - e^{-\delta\tau_{\nu,i}})$$

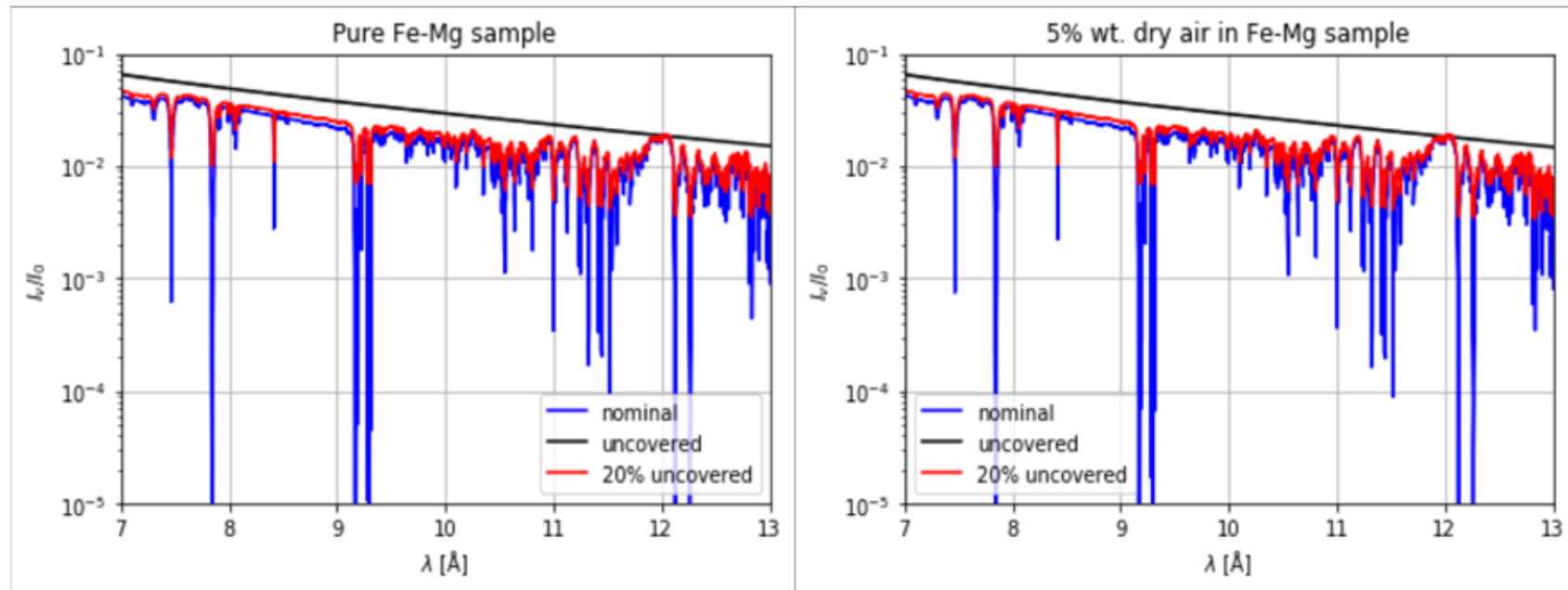
Spectral Synthesis



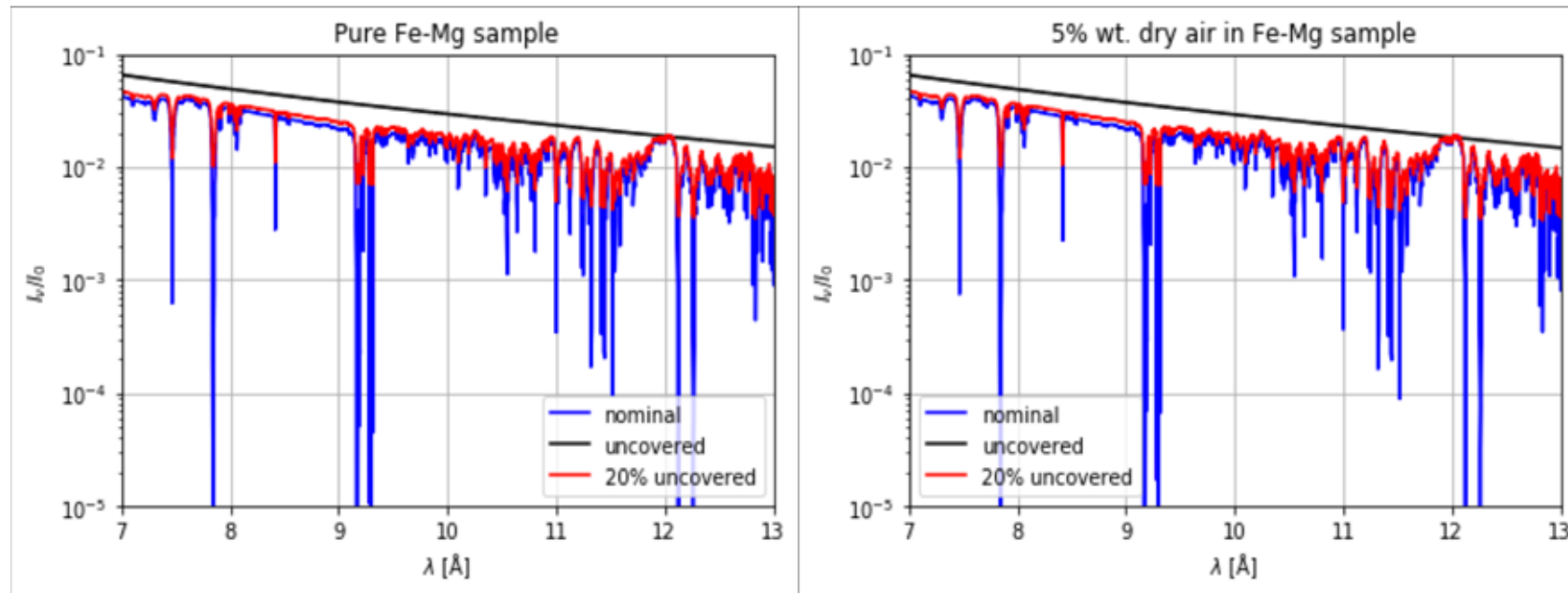
Equation of radiative transfer

$$\begin{aligned} \delta\tau_{\nu,i} &= \kappa_{\nu,i}\rho_i\delta z_i \\ I_{\nu,i} &= I_{\nu,i-1}e^{-\delta\tau_{\nu,i}} + S_{\nu,i}(1 - e^{-\delta\tau_{\nu,i}}) \\ S_{\nu,i} &= B_{\nu}(T_i) \end{aligned}$$

Transmissivity



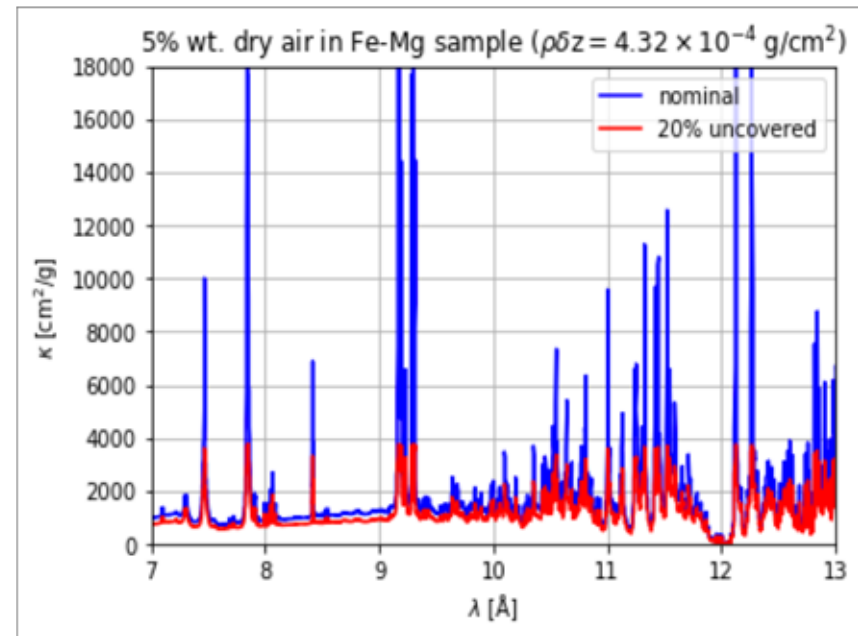
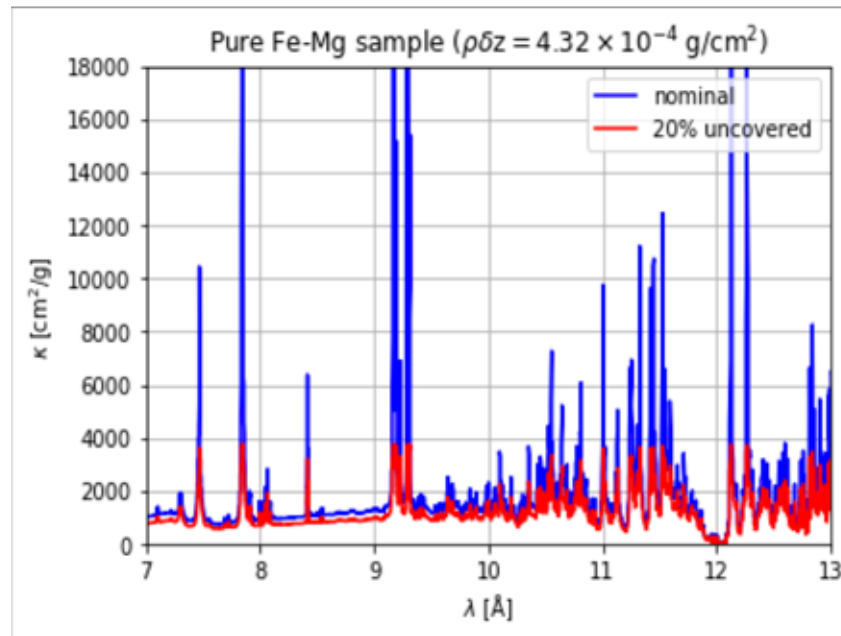
Transmissivity



Free-streaming of backlight through breaks in metal damps features

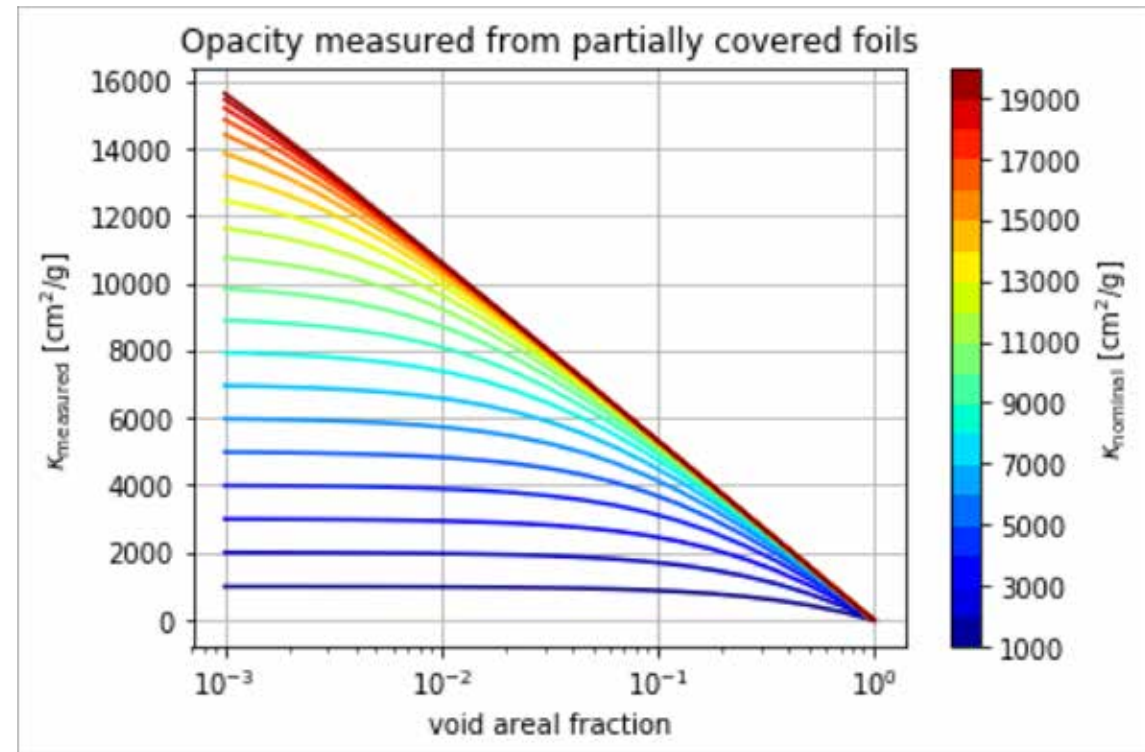
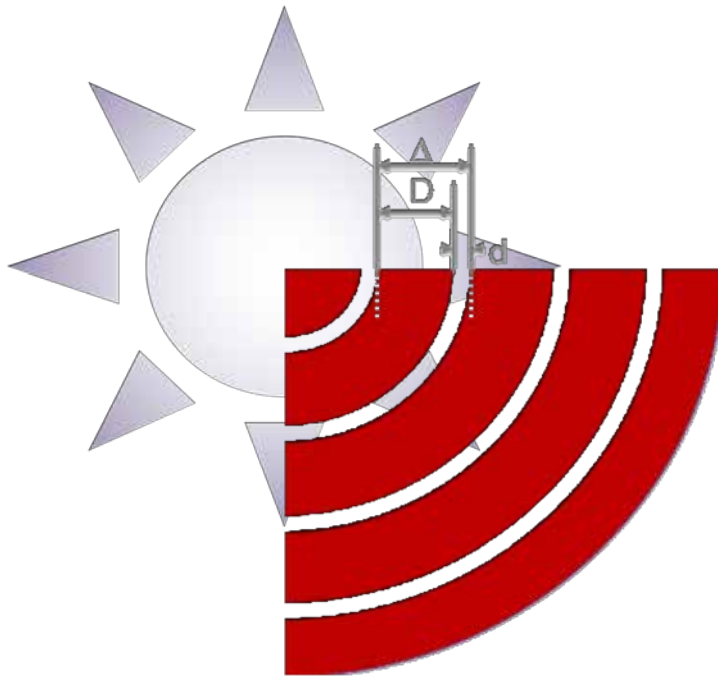
Opacity

$$I_\nu/I_0 = e^{-\kappa_\nu \rho \delta z}$$

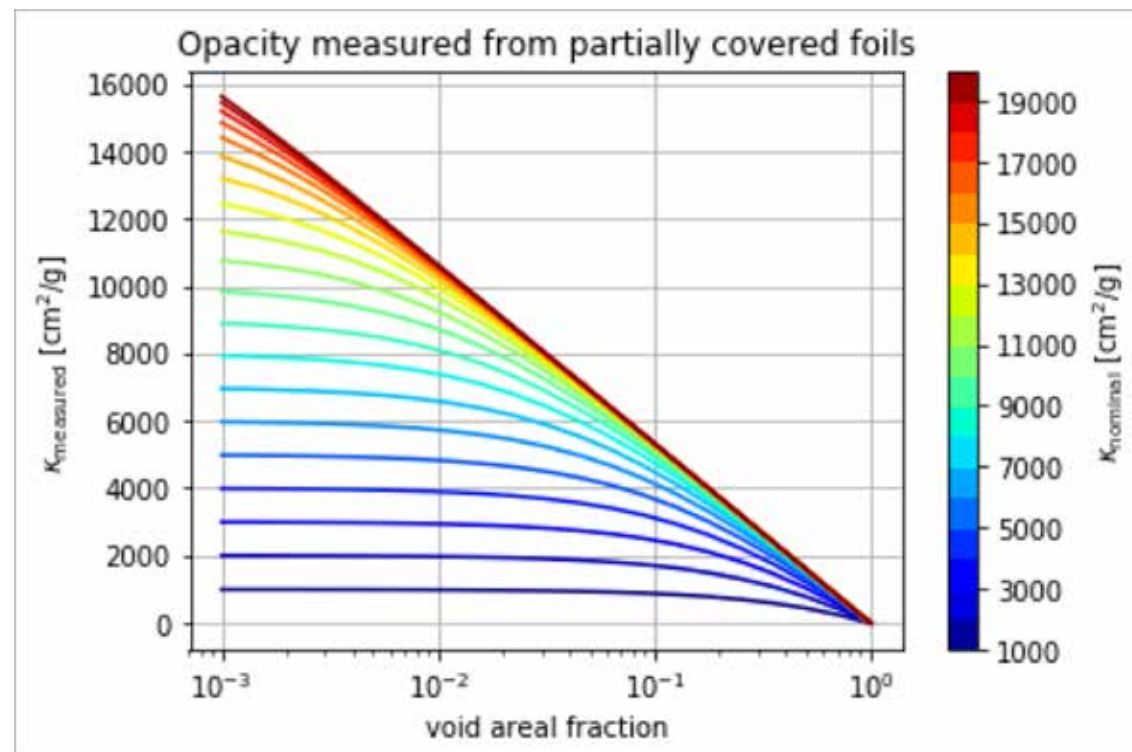
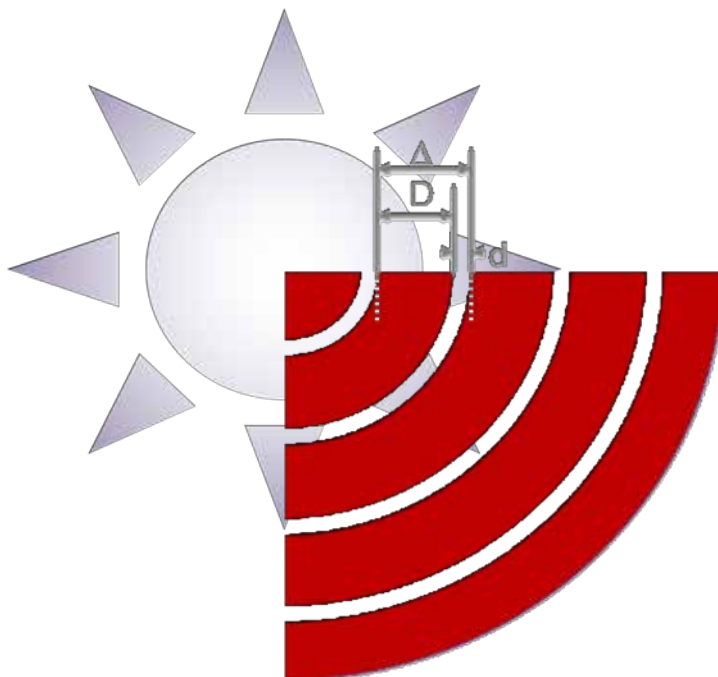


Free-streaming of backlight through breaks in metal damps features

Partial Covering



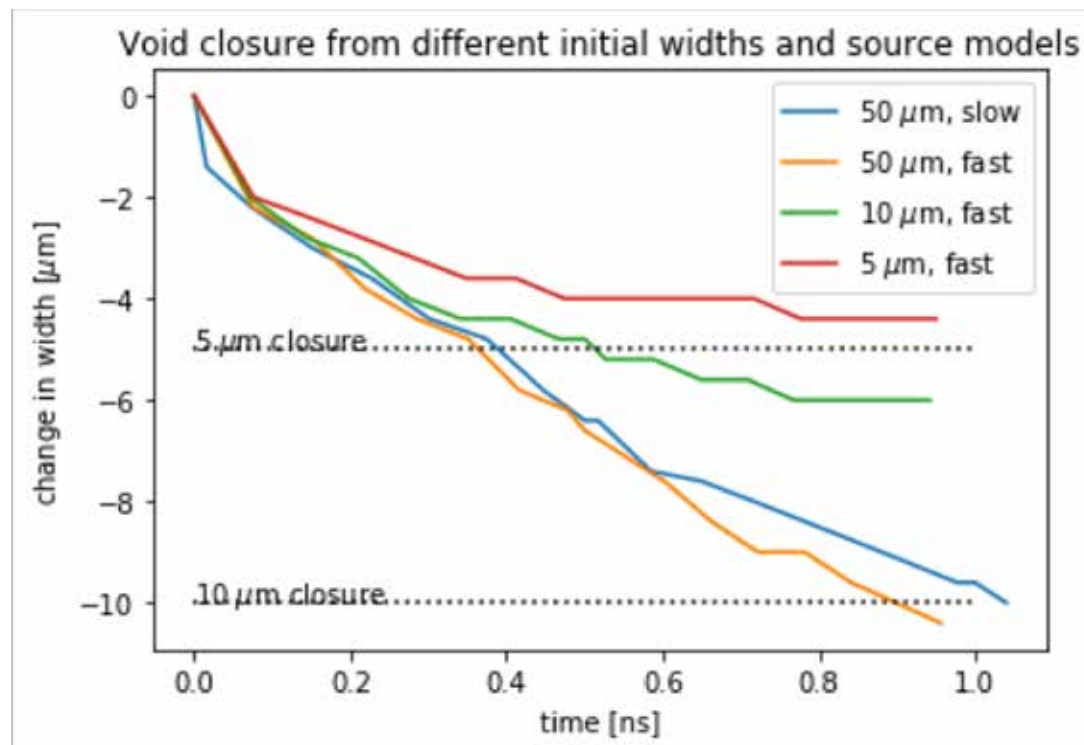
Partial Covering



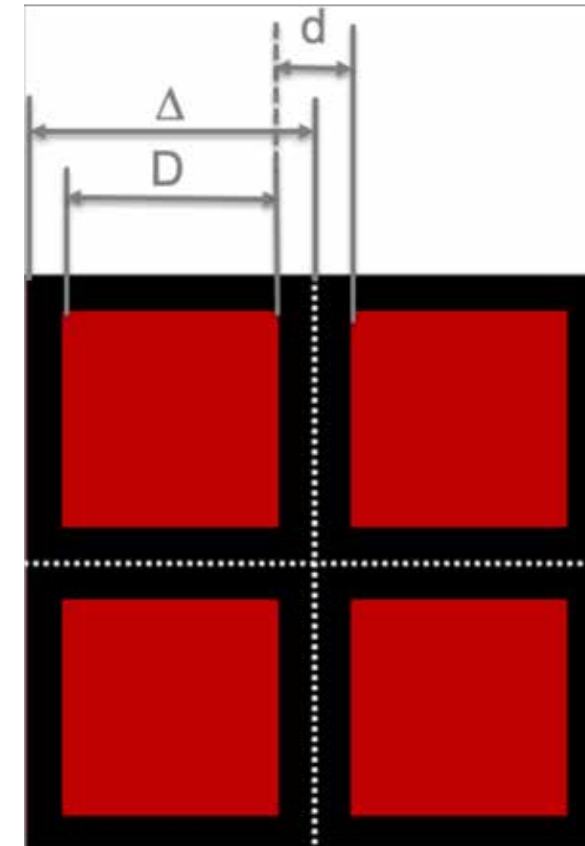
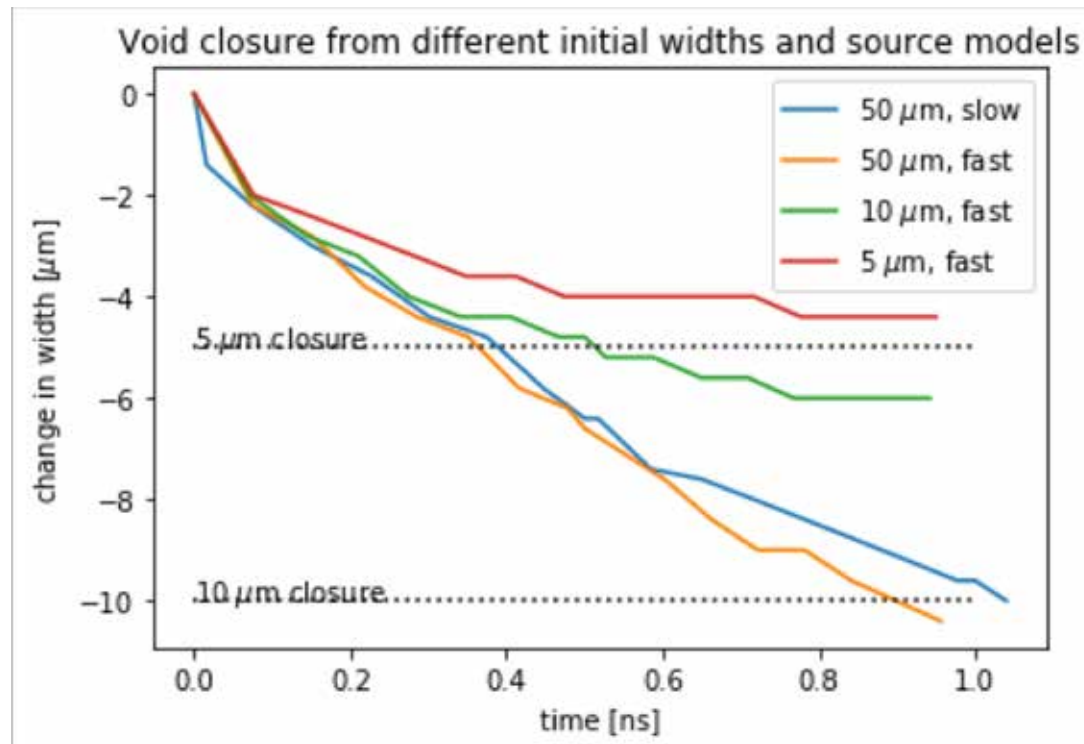
Damping of features is predictable

More damping by proportion for stronger features

Effectiveness of Self-Healing



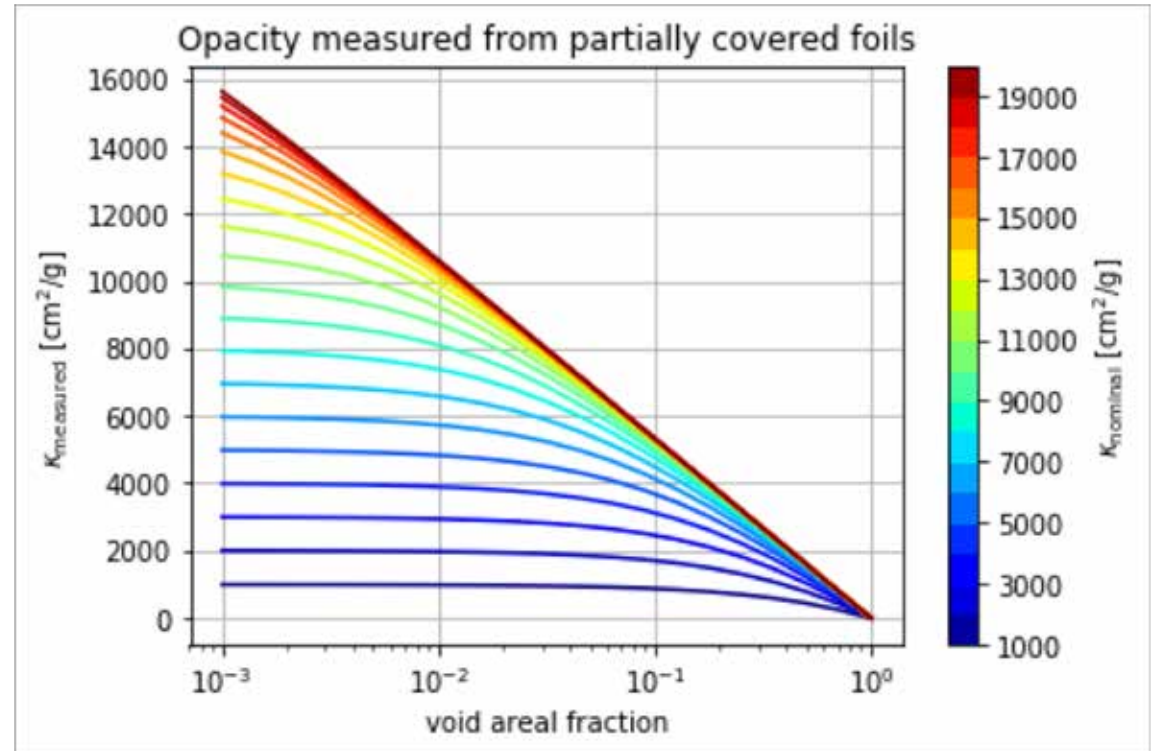
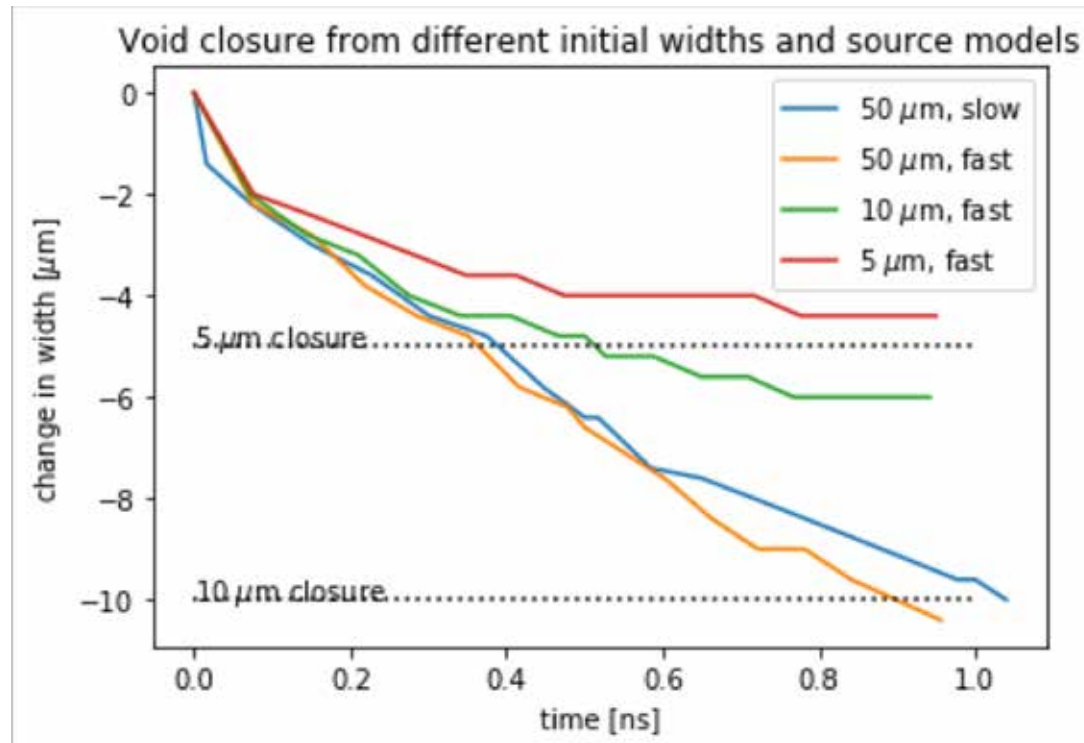
Effectiveness of Self-Healing



$$\%_{\text{uncovered}} = \left(2\frac{d}{\Delta} - \left(\frac{d}{\Delta} \right)^2 \right)$$

A few % uncovered persists for typical defect scenarios

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Summary

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Break in metal is the most effective defect model

Preheat explains the greatest variation between models

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Break in metal is the most effective defect model

Preheat explains the greatest variation between models

Without preheat

100 times higher tamper opacity than with 99 eV preheat

Short radiation MFP

Shallow sonic point of radiation heat front

Snowplow/ablation of tamper

Summary

Break in metal is the most effective defect model

Preheat explains the greatest variation between models

With preheat

Near-ideal volumetric heating and expansion

Summary

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Worse damping for larger nominal opacity

Damping is serious even at ~1 % areal coverage (surviving from the smallest visible defects) of the target by breaks

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Need to *precisely* characterize the metal sample at the backlight time to recover nominal opacity from defects

Shoot bad foils to test defect models, not to baseline new metal opacities

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Acknowledgments

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Thank you for your attention